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MONTICELLITE FROM SAN BERNARDINO COUNTY, CALIFORNIA, AND THE MONTICELLITE SERIES

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SUMMARY

Small grains of monticellite disseminated through a dolomite from the Dewey mine, Ivanpah Quadrangle, San Bernardino County, California, proved on analysis to be the purest of any described monticellite. The total percentage of other isomorphous bases, FeO and MnO, replacing the MgO, is less than 1.50. The indices of refraction, $\alpha=1.641$, $\beta=1.649$, $\gamma=1.655$ are likewise lower than those of any published measurements for the natural mineral.

The components of the isomorphous series $MgO \cdot CaO \cdot SiO_2$ (monticellite)-$FeO \cdot CaO \cdot SiO_2$-$MnO \cdot CaO \cdot SiO_2$ (glaucochroite) are discussed and their indices of refraction given as:

	α	β	γ	B	$2V$	Sign
$MgO \cdot CaO \cdot SiO_2$	1.641	1.646	1.652	.011	90°±	+?
$FeO \cdot CaO \cdot SiO_2$	1.696	1.734	1.743	.047	50°±	−
$MnO \cdot CaO \cdot SiO_2$	1.685	1.723	1.736	.051	61°	−

Their isomorphous mixtures in the monticellites from California (Dewey mine and Crestmore) and from Magnet Cove, Arkansas,

are calculated and comparisons made of the measured and calculated indices of refraction showing close agreement.

DESCRIPTION OF MINERAL

A sample of metamorphosed dolomite from the Dewey mine, Clark Mt. district, San Bernardino County, California, in the Ivanpah quadrangle, was collected by Dr. D. F. Hewett for study of its contained minerals.

According to Hewett, the Dewey mine lies about 1,000 feet southwest of the better known Copper World mine, which is about 6 miles east of Valley Wells on the Arrowhead highway. The Dewey mine includes two tunnels of which the longer, about 600 feet long, explores an area of Cambrian dolomite which is intruded by dikes and sills of gray fine-grained diorite. Near these sills the dolomite is locally altered to silicates and is thoroughly bleached. Monticellite forms round greenish, granular masses in white rather pure calcium carbonate. Black granular masses and small octahedra of spinel ($n=1.733$) and pink garnet ($n=1.736$ indicating grossularite) are common on the dump. In the lower tunnel, the 25 foot zone of carbonate rock overlying a sill of diorite shows considerable diopside, serpentine, deweylite, thaumasite and other ill-defined fine-grained silicates.

The specimen of dolomite studied contained disseminated small grains of monticellite and diopside and Hewett had recognized a narrow seam of thaumasite. A small quantity of the monticellite was separated from the rock by heavy solutions by Dr. C. S. Ross and its analysis is shown below in Table 1.

Table 1. Analysis and Ratios of Monticellite from the Dewey Mine, San Bernardino County, California

SiO_2	37.36	.62 or 1
MgO	24.90	.64 or 1
FeO	1.40	
MnO	0.04	
CaO	33.08	.59 or 1
H_2O-	0.04	
H_2O+	1.24	
Insoluble diopside	2.55	
	100.61	

The indices of refraction of the monticellite as measured, are somewhat lower than those usually given for this mineral and further study, with analysis, showed that this monticellite is the purest of any known occurrence, containing 96 per cent of $MgO \cdot CaO \cdot SiO_2$.

The ratios obtained from the small and not completely pure sample are close enough to a 1:1:1 ratio to show that the mineral is monticellite.

Optically, the mineral is biaxial, negative, $2V$ large (estimated 80°), with slight dispersion, $r>v$. The indices of refraction were measured independently by my colleagues, Dr. C. S. Ross and Miss J. J. Glass, with the following results[1] (Table 2).

TABLE 2. MEASURED INDICES OF REFRACTION OF MONTICELLITE FROM THE DEWEY MINE, CALIFORNIA

	α	β	γ	B
Ross	1.640	1.648	1.654	.014
Glass	1.641	1.649	1.655	.014
Schaller	1.642	1.649	1.655	.013
Average	1.641	1.649	1.655	.014

The purity of this monticellite means that the content of other isomorphous bases, as FeO and MnO, is a minimum and in harmony with this purity, the indices of refraction are lower than any determined on the natural mineral.

TABLE 3. TABULATION OF MEASURED INDICES OF REFRACTION OF MONTICELLITE, WITH OTHER DATA

No.	FeO	MnO	α	β	γ	B	$2V$	Sign
1	0	0	1.639	1.646	1.653	.014	80°–90°	+(?)
2	1.44	0.04	1.641	1.649	1.655	.014	80° ±	−
3	....	....	1.640	1.651	1.662	.022	Very large	−
4	3.98	0.52	1.646	1.654	1.661	.015	78°	−
5	4.79	1.63	1.651	1.662	1.668	.017	75°	−
6	5.11	1.17	1.650	1.662	1.667	.017	......	−
7	....	....	1.652	.....	1.669	.017	Fairly large	−
8	....	....	1.653	.....	1.668	.015	......	..
9	....	....	1.66±	.....	1.68±	.02	......	..

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[1] There is a striking similarity, except for sign, between the optical properties of this monticellite and the γ modification of calcium orthosilicate. Thus:

	α	β	γ	B	Sign	$2V$
Monticellite	1.641	1.649	1.655	.014	−	80°
γ-Ca_2SiO_4	1.642	1.645	1.654	.012	+	60°

The preceding tabulation (Table 3) of known measurements of indices of refraction of monticellite shows the variations. The percentages of FeO and MnO are those obtained after deduction of unessentials and recalculation of the analyses to 100 per cent.

REFERENCES

No. 1. Artificial $MgO \cdot CaO \cdot SiO_2$. Ferguson, J. B., and Merwin, H. E., The ternary system $CaO\text{-}MgO\text{-}SiO_2$: *Am. Jour. Sci.*, 4th ser., vol. **48**, p. 92, 1919.

2. Present paper.

3. Mineral "A" associated with merwinite from Crestmore, California. Larsen, E. S., and Foshag, W. F., Merwinite, a new calcium magnesium orthosilicate from Crestmore, California: *Am. Mineral.*, vol. **6**, p. 144, 1921. Referred to monticellite by Bowen, N. L., Two corrections to mineral data: *Am. Mineral.*, vol. **7**, p. 66, 1922, and by Tilley (Reference no. 9). The birefringence as given is too high. More accurate values, giving a birefringence of 0.015,[2] are given for this mineral under no. 4.

4. Crestmore, California. Moehlman, R. S., and Gonyer, F. A., Monticellite from Crestmore, California: *Am. Mineral.*, vol. **19**, pp. 474–476, 1934. Slight corrections of the indices of refraction are given in *Am. Mineral.*, vol. **20**, p. 138, 1935.

5. Magnet, Cove, Arkansas. Determinations by Penfield and Forbes. Penfield, S. L., and Forbes, E. H., Fayalite from Rockport, Mass., and on the optical properties of the chrysolite-fayalite group and of monticellite: *Am. Jour. Sci.*, 4th ser., vol. **1**, pp. 134–135, 1896.

6. Magnet Cove, Arkansas. Measured by Miss Glass.

7. Osborne, G. D., On the occurrence of custerite and monticellite in metamorphosed limestone from the Carlingford District, County South, Ireland: *Geol. Mag.*, vol. **69**, p. 62, 1932.

8. Bowen, N. L., Genetic features of alnoitic rocks at Isle Cadieux, Quebec: *Am. Jour. Sci.*, 5th ser., vol. **3**, pp. 3–4, 1922.

9. Tilley, C. E., A monticellite-nepheline-basalt from Tasmania: a correction to mineral data: *Geol. Mag.*, vol. **65**, p. 30, 1928. This monticellite was first erroneously described as a calcium silicate and named shannonite.

THE $MgO \cdot CaO \cdot SiO_2$ (MONTICELLITE)-$FeO \cdot CaO \cdot SiO_2$-$MnO \cdot CaO \cdot SiO_2$ (GLAUCOCHROITE) SERIES

GENERAL STATEMENT

The three analogous magnesium, iron, and manganese calcium orthosilicates, the first and third occurring as minerals—monticellite and glaucochroite—probably form a series of isomorphous mixtures, similar to the monoclinic pyroxene diopside-hedenbergite-johannsenite series or to the olivines. However, the only two members occurring as minerals are rare, glaucochroite being exceedingly so. Consequently, no mineral containing these three components in large proportions has yet been found. Such mixtures occur though, not rarely, in artificial furnace slags.

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[2] The corrected values (see under no. 4 for reference) of the indices of refraction give $\alpha = 1.6463$ and $\gamma = 1.6605$; hence the correct birefringence is 0.0142. The indices, as given in this paper, are given only to three decimals and if the fourth decimal is 5 (or greater), the third decimal is increased by 1.

In the following pages, a discussion is presented, aiming to give as accurately as possible the indices of refraction of the three components and then to discuss their intermediate isomorphous mixtures where these occur as minerals. This discussion, however, is brief as the isomorphous mixtures of which the chemical composition and the indices of refraction are known, are limited to the two monticellites from California (Dewey mine and Crestmore) and that from Magnet Cove, Arkansas.

The indices of refraction of pure $MgO \cdot CaO \cdot SiO_2$ are first calculated from the known data for these three occurrences of monticellite. This involves the indices for the analogous iron and manganese components and the derivation of these values is given after the discussion of those of the magnesium component. The values of the iron component have been determined on artificial material. Two analyses of glaucochroite, one containing a little MgO, are used for the calculation of the indices of refraction of the pure manganese component.

$MgO \cdot CaO \cdot SiO_2$ (MONTICELLITE)

The indices of refraction for pure (artificial) $MgO \cdot CaO \cdot SiO_2$ generally accepted are: $\alpha = 1.639$ $\beta = 1.646$, $\gamma = 1.653$, $B = .014$, representing the average of the values given by Ferguson and Merwin,[3] who give a range for α from 1.638 to 1.640 and for γ from 1.651 1.655.

The monticellites from the Dewey mine, from Crestmore,[4] and from Magnet Cove, are so dominantly $MgO \cdot CaO \cdot SiO_2$ (at least 84 weight percentage), that the indices of refraction for pure $MgO \cdot CaO \cdot SiO_2$ can be calculated from the measured values, allowing for the small quantities of the analogous iron and manganese components, whose indices are known.

The results obtained are as follows (Table 4).

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[3] Ferguson, J. B., and Merwin, H. E., The ternary system CaO-MgO-SiO_2: *Am. Jour. Sci.*, 4th ser., vol. **48**, p. 92, 1919.

[4] Moehlman, R. S., and Gonyer, F. A., Monticellite from Crestmore, California: *Am. Mineral.*, vol. **19**, pp. 474–476, 1934. Slight corrections of the indices of refraction are given in *Am. Mineral.*, vol. **20**, p. 138, 1935.

TABLE 4. CALCULATED INDICES OF REFRACTION OF PURE $MgO \cdot CaO \cdot SiO_2$, AS OBTAINED FROM THE DATA ON NATURAL MONTICELLITES

Mineral	Composition			Indices of refraction	
	$MgO \cdot CaO \cdot SiO_2$	$FeO \cdot CaO \cdot SiO_2$	$MnO \cdot CaO \cdot SiO_2$	Measured	Calculated for $MgO \cdot CaO \cdot SiO_2$
Dewey mine, California	96	4	0	$\alpha=1.641$ $\beta=1.649$ $\gamma=1.655$ $B=.014$	$\alpha=1.639$ $\beta=1.645$ $\gamma=1.651$ $B=.012$
Crestmore, California	88	10½	1½	$\alpha=1.646$ $\beta=1.654$ $\gamma=1.661$ $B=.015$	$\alpha=1.640$ $\beta=1.643$ $\gamma=1.649$ $B=.009$
Arkansas (Penfield and Forbes)	84	12	4	$\alpha=1.651$ $\beta=1.662$ $\gamma=1.668$ $B=.017$	$\alpha=1.643$ $\beta=1.649$ $\gamma=1.654$ $B=.011$
Arkansas (Miss Glass)	84	13	3	$\alpha=1.650$ $\beta=1.662$ $\gamma=1.667$ $B=.017$	$\alpha=1.642$ $\beta=1.649$ $\gamma=1.652$ $B=.010$

The average of the available data, summarized in Table 5, gives the values: $\alpha=1.641$, $\beta=1.646$, $\gamma=1.652$; $B=0.011$, which values are used in the discussion of the natural monticellites on the following pages.

TABLE 5. INDICES OF REFRACTION OF $MgO \cdot CaO \cdot SiO_2$

	α	β	γ	B
Artificial	1.639	1.646	1.653	0.014
Calculated from measurements of monticellite from:				
Dewey mine	1.639	1.645	1.651	0.012
Crestmore	1.640	1.643	1.649	0.009
Arkansas (P. & F.)	1.643	1.649	1.654	0.011
Arkansas (G.)	1.642	1.649	1.652	0.010
Average	1.641	1.646	1.652	0.011

The average values given above are almost identical with the previously accepted values, determined on artificial material. They are believed to be slightly more accurate as the birefringence of pure $MgO \cdot CaO \cdot SiO_2$ (0.011) should be less than that found for the mineral from the Dewey mine (0.014) and from Crestmore (0.015). Both these minerals contain small quantities of the analagous iron component, $FeO \cdot CaO \cdot SiO_2$, whose birefringence (0.047) is strong and about four times that of $MgO \cdot CaO \cdot SiO_2$, so that the presence of a small quantity of $FeO \cdot CaO \cdot SiO_2$ in a monticellite rapidly increases the birefringence.

The calculated values of the indices of refraction for $MgO \cdot CaO \cdot SiO_2$ for the different occurrences (Table 4) show a greater variation than was expected; thus the maximum difference for α is 0.004, for β 0.006, and for γ 0.005. The birefringence however is consistently lower than 0.014, ranging from 0.009 to 0.012.

$FeO \cdot CaO \cdot SiO_2$

The indices of refraction for the artificial compound $FeO \cdot CaO \cdot SiO_2$ (not known as a mineral), are given by Bowen, Schairer, and Posnjak[5] as: $\alpha = 1.696$, $\beta = 1.734$, $\gamma = 1.743$, with $B = 0.047$. These values are close to the indices of glaucochroite, but slightly higher. They confirm the results found previously for the monoclinic pyroxenes hedenbergite and johannsenite, namely, that in analogous or isomorphous series, the indices of refraction of the iron component are slightly higher than those of the manganese component, but the birefringence is slightly less.

$MnO \cdot CaO \cdot SiO_2$ (GLAUCOCHROITE)

Only three analyses of glaucochroite have been published—the original one by Penfield and Warren,[6] a later one by Palache,[7] and a third analysis made by R. B. Gage and listed by Palache in his Franklin report.[8]

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[5] Bowen, N. L., Schairer, J. F., and Posnjak, Eugene, The system, Ca_2SiO_4-Fe_2SiO_4: *Am. Jour. Sci.*, 5th ser., vol. **25**, pp. 287–288, 1933. Also, The system, CaO-FeO-SiO_2: *Am. Jour. Sci.*, 5th ser.,vol. **26**, p. 262, 1933. The value for β is calculated from α, γ, and $2V$.

[6] Penfield, S. L., and Warren, C. H., Some new minerals from the zinc mines at Franklin, New Jersey, and note concerning the chemical composition of ganomalite: *Am. Jour. Sci.*, 4th ser., vol. **8**, p. 339, 1899.

[7] Palache, Charles, Mineralogical notes on Franklin and Sterling Hill, New Jersey: *Am. Mineral.*, vol. **13**, pp. 307–308, 1928. Analysis by Dr. L. H. Bauer.

[8] Palache, Charles, The minerals of Franklin and Sterling Hill, Sussex County, New Jersey: *U. S. Geol. Survey*, Prof. Paper **180**, p. 79, 1935.

The indices of refraction given by Penfield and Warren are: $\alpha=1.686$, $\beta=1.722$, $\gamma=1.735$.[9] $2V=61°$. The only extraneous base given in the analysis is 1.74 per cent of PbO, the interpretation of which is difficult as the 38.00 per cent MnO reported already slightly exceeds the theoretical percentage of MnO (37.90) in glaucochroite. Nasonite is reported as an associated mineral and it would require only 2.6 per cent of nasonite to yield the 1.74 per cent of PbO reported. No MgO is reported in the analysis.

The indices of refraction given, therefore, probably represent those of pure glaucochroite.

The second reported analysis, by Bauer, as published by Palache, is given after 3.29 per cent willemite (based on the ZnO content) is deducted and the analysis recalculated to 100 per cent. In this form, the analysis still contains 0.32 per cent PbO and 0.98 per cent Al_2O_3. If these two bases are also deducted and the analysis recalculated to 100 per cent, the following composition is obtained (Table 6).

TABLE 6. RECALCULATED ANALYSIS OF GLAUCOCHROITE AFTER DEDUCTING IMPURITIES

[L. H. BAUER ANALYST]

SiO_2	32.34		
MnO	34.75		
FeO	0.11	Composition $MnO \cdot CaO \cdot SiO_2$	91 per cent
MgO	2.34	$MgO \cdot CaO \cdot SiO_2$	9 per cent
CaO	30.46		100
	100.00		

The small percentage of MgO present is due to isomorphous $MgO \cdot CaO \cdot SiO_2$, and calculation shows that Bauer's recalculated analysis can be interpreted as representing an isomorphous mixture with 9 per cent of monticellite.

The indices of refraction of glaucochroite given by Larsen and Berman[10] on "Type material" probably were made on the material analyzed by Bauer, as the indices are very close to the less exact ones previously determined by Berman and published by Palache,[11] as the following comparison shows (Table 7):

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[9] The two indices α and β determined by the prism method and γ calculated from α, β, and $2E$ (measured).

[10] Larsen, E. S., and Berman, Harry. The microscopic determination of the nonopaque minerals, 2d ed.: *U. S. Geol. Survey*, Bull. **848**, p. 191, 1934.

TABLE 7. INDICES OF REFRACTION OF GLAUCOCHROITE ANALYZED BY L. H. BAUER

Larsen and Berman, 1934		Berman, 1928	
α	1.679	α	1.68
β	1.716	β	1.71
γ	1.729	γ	1.725
B	.050	B	.045

The indices of refraction for the pure compound $MnO \cdot CaO \cdot SiO_2$ calculate out as: $\alpha = 1.683$, $\beta = 1.723$, $\gamma = 1.736$, using the more exact determinations given by Larsen and Berman for a mineral composed of 91 per cent of $MnO \cdot CaO \cdot SiO_2$ and 9 per cent of $MgO \cdot CaO \cdot SiO_2$. These values are remarkably close to those given by Penfield and Warren and averaging them, the following values (Table 8) are obtained which are taken as representing the indices of refraction for pure glaucochroite.

TABLE 8. INDICES OF REFRACTION OF PURE GLAUCOCHROITE

	α	β	γ	B
Penfield and Warren	1.686	1.722	1.735	.049
Recalculated, based on Bauer's analysis	1.683	1.723	1.736	.053
Average	1.685	1.723	1.736	.051

The indices of refraction ($\alpha = 1.685$, $\beta = 1.7105$, $\gamma = 1.7205$, with $B = .0355$), given by Greer[12] for artificial glaucochroite do not agree closely with those just given. The value for α is identical but γ is low and the birefringence given by him is much too low.

ISOMORPHOUS MIXTURES OF THE THREE COMPONENTS

The calculated chemical composition and the optical properties of the three components, $MgO \cdot CaO \cdot SiO_2$, $FeO \cdot CaO \cdot SiO_2$, and $MnO \cdot CaO \cdot SiO_2$, are given in Table 9.

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[11] Palache, Charles, Mineralogical notes on Franklin and Sterling Hill, New Jersey: *Am. Mineral.*, vol. **13**, p. 307, 1928.

[12] Greer, W. L. C., Mix-crystals of Ca_2SiO_4 and Mn_2SiO_4: *Am. Mineral.*, vol. **17**, p. 138, 1932.

TABLE 9. CALCULATED CHEMICAL COMPOSITION AND OPTICAL PROPERTIES OF COMPONENTS

	$MgO\cdot CaO\cdot SiO_2$	$FeO\cdot CaO\cdot SiO_2$	$MnO\cdot CaO\cdot SiO_2$
SiO_2	38.40	31.97	32.12
MgO	25.76	.....	.....
MnO	.....	.....	37.90
FeO	.....	38.19	.....
CaO	35.84	29.84	29.98
	100.00	100.00	100.00
α	1.641	1.696	1.685
β	1.646	1.734	1.723
γ	1.652	1.743	1.736
B	.011	.047	.051
2*V*	Nearly 90°	50°±2°	61°
Sign	+?[a]	—	—

[a] Natural monticellites are optically negative with 2*V* large.

The comparison of the measured and calculated indices of refraction for the monticellite from the Dewey mine, California, is shown in Table 10. In this and the following comparisons, the analyses have been recalculated to 100 per cent after deduction of unessential constituents. The composition is expressed by weight percentages of the components.

In the monticellite from Crestmore, California, described in de-

TABLE 10. COMPARISON OF MEASURED AND CALCULATED INDICES OF REFRACTION OF MONTICELLITE FROM THE DEWEY MINE, SAN BERNARDINO COUNTY, CALIFORNIA

SiO_2	38.60
MgO	25.73
FeO	1.44
MnO	0.04
CaO	34.19
	100.00

Composition	
$MgO\cdot CaO\cdot SiO_2$	96
$FeO\cdot CaO\cdot SiO_2$	4
	100

Indices of refraction

Measured		Calculated	
α	1.641	α	1.643
β	1.649	β	1.650
γ	1.655	γ	1.656
B	.014	*B*	.013

tail by Moehlman and Gonyer,[13] the quantities of FeO and MnO, isomorphously replacing the MgO, are greater than those in the monticellite from the Dewey mine, but less than those in the mineral from Magnet Cove, Arkansas.

The calculated analysis, with component composition, and measured and calculated indices of refraction, are given in Table 11.

TABLE 11. COMPARISON OF MEASURED AND CALCULATED INDICES OF REFRACTION OF MONTICELLITE FROM CRESTMORE, CALIFORNIA

SiO_2	37.48	Composition	$MgO \cdot CaO \cdot SiO_2$	88
MgO	22.80		$FeO \cdot CaO \cdot SiO_2$	$10\frac{1}{2}$
FeO	3.98		$MnO \cdot CaO \cdot SiO_2$	$1\frac{1}{2}$
MnO	0.52			100
CaO	35.22			
	100.00			

Indices of refraction

Measured		Calculated	
α	1.646	α	1.647
β	1.654	β	1.656
γ	1.661	γ	1.663
B	.015	B	.016

Three analyses of monticellite from Magnet Cove, Arkansas, are available, one by Genth,[14] one by Penfield and Forbes,[15] who also give $2V=75°$ (measured) and $2V=74°$ (calculated from the indices), and one by Himmelbauer as given by Tschermak.[16]

All three analyses are very similar (FeO=5.25, 4.75, 5.08; MnO=1.17, 1.62, 0.66) so that, after deduction of unessentials and recalculation to 100 per cent, the average analysis must represent closely the composition of this monticellite from Magnet Cove. This average composition is used for a comparison of the indices of refraction measured by Miss J. J. Glass on a specimen of monticellite from Magnet Cove collected by Dr. C. S. Ross.

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[13] Moehlman, R. S., and Gonyer, F. A., Monticellite from Crestmore, California: *Am. Mineral.*, vol. **19**, pp. 474–476, 1934. Slight corrections of the indices of refraction, vol. **20**, p. 138, 1935.

[14] Genth, F. A., Contributions to mineralogy, No. 50 (with crystallographic notes by S. L. Penfield and L. V. Pirsson): *Am. Jour. Sci.*, 3d ser., vol. **41**, pp. 398–400, 1891.

[15] Penfield, S. L., and Forbes, E. H., Fayalite from Rockport, Mass., and on the optical properties of the chrysolite-fayalite group and of monticellite: *Am. Jour. Sci.*, 4th ser., vol. **1**, pp. 134–135, 1896.

[16] Tschermak, G., Metasilikate und Trisilikate: *Sitzungsber. math.-naturw. Kl., Akademie d. Wissenschaften*, Wien, vol. **115**, Abt. 1, p. 221, 1906.

The comparisons of measured and calculated indices are shown below in Table 12.

TABLE 12. COMPARISON OF MEASURED AND CALCULATED INDICES OF REFRACTION OF MONTICELLITE FROM MAGNET COVE, ARKANSAS

	Penfield and Forbes		Average of three analyses	
SiO_2	37.13		36.33	
MgO	21.81		22.50	
FeO	4.79		5.11	
MnO	1.63		1.17	
CaO	34.64		34.89	
	100.00		100.00	
Composition $MgO \cdot CaO \cdot SiO_2$	84		84	
$FeO \cdot CaO \cdot SiO_2$	12		13	
$MnO \cdot CaO \cdot SiO_2$	4		3	
	100		100	
	Measured[a]	Calculated	Measured[b]	Calculated
α	1.651	1.650	1.650	1.649
β	1.662	1.660	1.662	1.660
γ	1.668	1.667	1.667	1.666
B	.017	.017	.017	.017

[a] Measured by Penfield and Forbes on material analyzed.

[b] Measure by Miss Glass on unanalyzed material collected by Dr. C. S. Ross.

The measured and calculated indices of refraction of these monticellites agree within 0.002 for all the comparisons. The close agreement between the birefringence as obtained from the measured and calculated indices confirms the suggestion earlier made that 0.014 is too high for pure $MgO \cdot CaO \cdot SiO_2$ and that 0.011 is more nearly correct.

ARTIFICIAL MONTICELLITE FROM FURNACE SLAGS

An attempt was made to interpret the data listed by Beliankin and Ivanov[17] for various artificial monticellites from furnace slags.

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[17] Beliankin, D., and Ivanov, B., The system of monticellite: *Am. Jour. Sci.*, 5th ser., vol. **22**, pp. 72–80, 1931.

The results were very unsatisfactory, a condition the authors themselves acknowledge, as they call attention to the small number (2 out of 7 if the monticellite from Arkansas and glaucochroite from New Jersey be omitted) in which the ratio of $MgO+FeO+MnO$ to CaO is approximately 1:1. Furnace slags are apt to be very impure in composition and the analyses listed suggest the possibility that in this series, CaO-free compounds, such as $FeO\cdot FeO\cdot SiO_2$, may enter as components into these monticellite-like slags. The presence of such compounds in natural minerals of this series is not indicated by their analyses, though their number is far too small to draw a general conclusion.

For the slag from the Ural Mountains, described by Beliankin and Ivanov,[18] the percentage of CaO (28.41 as given in the analysis or 30.56 in the recalculated analysis) is too low for an isomorphous mixture of the three components $MgO\cdot CaO\cdot SiO_2$, $MnO\cdot CaO\cdot SiO_2$, $FeO\cdot CaO\cdot SiO_2$, whose content of CaO ranges from 29.84 per cent to 35.84 per cent

Their material consists of 51 per cent of $MgO\cdot CaO\cdot SiO_2$, 21 per cent of $FeO\cdot CaO\cdot SiO_2$, and 28 per cent of $MnO\cdot CaO\cdot SiO_2$, if calculated out on the assumption that only components of the $RO\cdot CaO\cdot SiO_2$ type are present. On this basis, α is calculated as 1.665, agreeing well with their measured value (1.666), but γ calculates out as 1.695 whereas they give the much lower value $\gamma=1.682$. The birefringence should be nearly twice as great as the value 0.016 obtained from their measured indices of refraction.

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[18] *Op. cit.*, pp. 77–80.

SCHILLER STRUCTURE

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Oriented, rod-like, needle-like, tabular or platy, granular and "dust" inclusions, distributed along two or more intersecting planes, are common in certain minerals of the plutonic rocks such as gabbros and related deep-seated types. The structures formed by such oriented inclusions have been called "schiller structures" by various observers, including the writer (7), regardless of the mineral species containing them. In many cases, however, these inclusions do not impart that peculiar chatoyance, or sheen, to the crystals which act as host for them, which the writer considers essential for a true schiller effect, so that it seems pertinent to inquire into the usage of the term "schiller" in connection with some of these occurrences.

The expression originated with the old German miners, who called certain minerals "schiller-spath" that were iridescent when light was reflected from them at certain angles.

Werner (1749–1817) used the term, according to Karl von Raumer (30),[1] who mentions the "schiller-spar of Werner" and who selected, himself, the name "schillerfels" as a designation for a rock-group composed of "early greenstone" and gabbro because ". . . it is composed of those rocks which have an iridescence, and also because Werner's schiller-spar is an oryktognostic (sic) constituent" (p. 40; translation).

Haüy (12) employed the term "schillerspath" as a mineral name for those minerals exhibiting iridescence, and "schillerstein" as the rock-name for rocks containing "schillerspath." Scheerer (23), Streng (25), Des Cloiseau (8) and Hagge (10) used such terms as "schillerfels" and "schillerspath" in about the same sense as the words were employed by Haüy, applying the expressions to certain types of pyroxene; but none of these writers used the word "schiller" as an expression descriptive of inclusion-structures.

Iridescence displayed by various feldspars has been studied by numerous investigators, some of whom used the term "schiller" in connection with the phenomenon, whereas others did not use the word. Von Bonsdorf (28), Scheerer (23), Vogelsang (27),[2] and

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[1] Numerals refer to titles listed in alphabetical order at the end of this paper.

[2] Vogelsang referred the golden and reddish colors to reflections from included mineral microlites, but the blue color was considered to be a polarization phenomenon produced by light reflected from planes.

Andersen (2) ascribe the chatoyance of certain feldspars to reflection of light from inclusions, whereas Brewster (5) thought that the iridescence might be due to

> . . . crystallized laminae disseminated through the felspar, and giving the colors of thin plates; or they may be slender crystals, which, like the veins of calcareous-spar, develop the tints of polarized light; or they may be crystallized cavities, either entirely empty, or containing solid, fluid, or gaseous substances (p. 324).

Von Hessel (29), Senff (24), Nordenskjöld (17), Zirkel (32), Reusch (19), Bøggild (4),[3] and Parsons (18) believed that the color phenomena are due to reflection of light from planes, of one sort or another, within the crystals, with consequent polarization.

Cathrein (6), Williams (31), Hobbs (13), Tertsch (26), Rogers (20) and Rosenbusch (22)[4] describe oriented inclusions in hornblende in considerable detail, but none of these authors referred to such structures, in hornblende, as "schiller structures." Other writers, however, among whom are Haidinger (11), Rose (21), Kosmann (16), Zirkel (32), Judd (15), and Williams (31) refer to "schiller" or "schillerization" in their descriptions of pyroxene; and Hutton (14), Bancroft (3), Agar (1) and the writer (7) describe oriented inclusions in hornblende, allude to the structures formed by the inclusions as "schiller" structures, or refer to "schillerization" as a phenomenon caused by the inclusions described.

The concept of "schillerization" as a *process* that might affect minerals of different species was first set forth by Judd (15), who considered the phenomenon to be due to a deep-seated secondary alteration of pyroxene and allied minerals along "solution-planes" with the production of solution-cavities within the crystals, commonly filled with the products of alteration; thus:

> . . . these enclosures are of the nature of *negative crystals* which are more or less completely filled with products of decomposition of the mineral. When these negative crystals are completely filled with foreign substances, the enclosures assume the outlines of true crystals, though they do not, of course, exhibit their optical properties (p. 384).

The chatoyance displayed by crystals so affected was ascribed to the polarization of light reflected from these minute, filled, secondary "negative" cavities. Judd believed that the filling consisted of "hydrated oxides like chalcedony, opal, göthite and limonite" (p. 387).

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[3] Bøggild coined the term "labradorization" as a substitute for "schiller" in connection with his study of iridescence in feldspars.

[4] In an earlier edition of Rosenbusch's work (1907) the term "schiller" was, however, used in connection with the description of inclusions in hornblende; and he does use the term in connection with pyroxene.

Thus there seems to have been no very consistent usage of the term "schiller," for the expression, in one form or another, has been employed in the description of iridescent effects displayed by different minerals, for microstructures produced by oriented inclusions in minerals which commonly exhibit no iridescence at all, and as both mineral and rock names; and the phenomenon of iridescence has been variously ascribed to reflection of light, with consequent polarization, from planes within the crystals, from crystal inclusions, and from filled negative cavities.

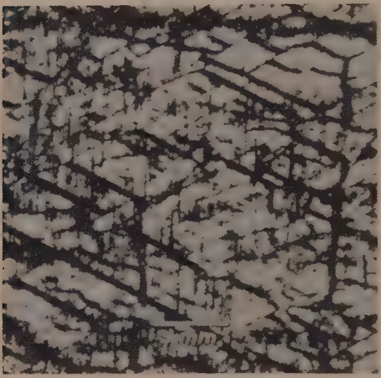

FIG. 1. Hornblende in hornblendic pyroxenite, near Humacao, Puerto Rico, ordinary light; the scale is 0.10 mm. Showing magnetite plates or rods oriented parallel to (010) and bisecting the prismatic cleavages. Magnetite is distributed along cleavage planes also. No iridescence is displayed by the hornblende in this rock, so that for the term "schiller" the writer proposes to substitute the term "endoblastic" in the description of such structure.

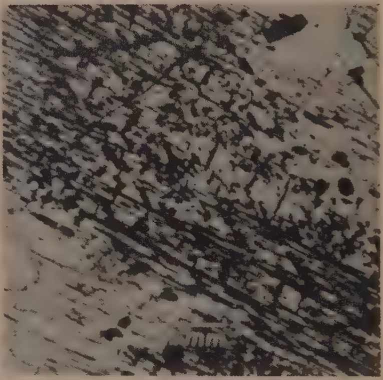

FIG. 2. Oriented magnetite inclusions in the hornblende of a diorite that occurs about one mile west of West Torrington, Conn., ordinary light; the scale is 0.10 mm. This structure was called "schiller structure" by Agar (1), but no iridescence is displayed. Another example of "endoblastic" structure.

The writer has observed oriented crystal inclusions of magnetite or ilmenite in the hornblende of various rocks to which he has referred as "schiller structure" or "schillerization effects"; incorrectly, as he now believes. Figures 1 to 3 illustrate such inclusions. Figure 1 shows plates or rods of magnetite in hornblende, oriented parallel to (010), bisecting the angles made by the prismatic cleavages and intersecting another set of the same kind of inclusions distributed along the cleavage directions. The rock is a hornblendic pyroxenite from Puerto Rico (7). Not one of the thin sections examined contained hornblende that was even slightly iridescent in incident light, although a few crystals returned a very weak white-light reflection from some of the inclusions; no real chatoyance was observed, however. Figure 2 shows oriented magnetite inclusions in the hornblende of a diorite from Connecticut described by Agar (1). None of the hornblende in the section examined by the writer[5] displayed iridescence in incident light. Nor does any of the

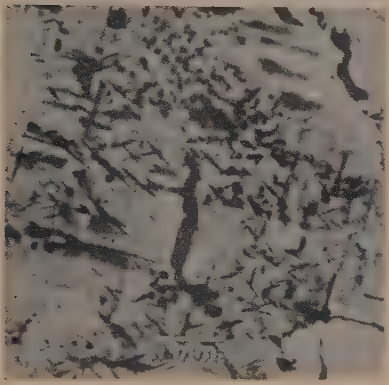

FIG. 3. Oriented inclusions of magnetite and biotite in the hornblende of a norite from the Cortlandt series, ordinary light; the scale is 0.10 mm. The hornblende in this rock displays no iridescence whatever, although the hyperthene (Fig. 6) exhibits very spectacular schiller effects. These are merely oriented inclusions in the hornblende, to which the term "schiller" should not be applied. Typical "endoblastic" structure.

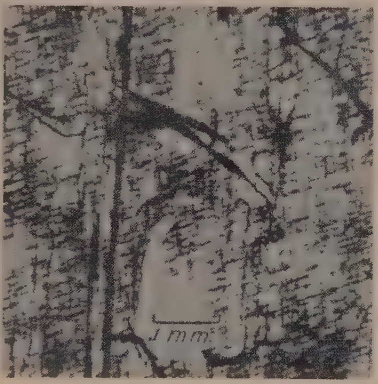

FIG. 4. Pyroxene in magnetiferous pyroxenite, near Humacao, Puerto Rico, ordinary light; the scale is 0.10 mm. Brownish films distributed along parting or "solution" planes. These planes are slightly oblique to the thin section, so that the traces of them shown in the photomicrograph appear wider than is actually the case. Incident light is reflected from such areas in this rock with faint iridescence. A schiller *effect* is produced, but the writer would call the *structure* "endoblastic."

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[5] Through the courtesy of Dr. Agar.

hornblende, illustrated in Figure 3, in a norite from the Cortlandt Series, show iridescence, although fifteen thin sections of the rock were examined. In the same thin sections, however, beautifully pleochroic hypersthene displays spectacular iridescence, which is connected with extremely thin, reddish-brown "films" or scales, distributed along so-called "solution-planes" or parting planes, illustrated in Figure 6. The iridescence may be best observed under the microscope, using strong oblique illumination directed downward on the surface of the thin-section. The intensity and brilliance of the phenomenon is dependent in part on the orientation of the hypersthene in the section, in part on the inclination of the "films" with respect to the surface of the mineral grain and in part on the level within the thin section at which the "films" may happen to lie; for many grains of hypersthene in the same sections, and containing the same sets of "films," display no iridescence at all under the same condition of illumination.

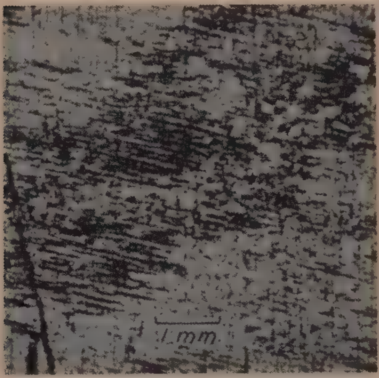

Fig. 5. Diallage in an olivine gabbro from Minnesota, ordinary light; the scale is 0.10 mm.

Showing thin films along parting planes. These are not magnetite inclusions. Such inclusions in the pyroxene of this rock exhibit faint to more or less pronounced iridescence in grains which are favorably oriented. An "endoblastic" *structure* productive of schiller *effects*.

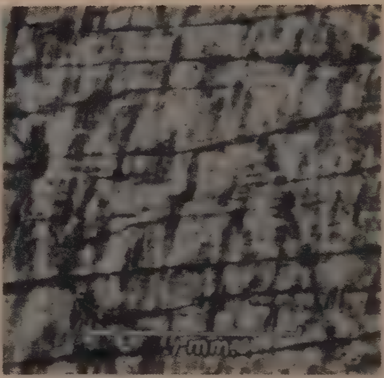

Fig. 6. Hypersthene in the same norite which contains the hornblende shown in Fig. 3, ordinary light; the scale is 0.10 mm. This crystal exhibits very spectacular and striking iridescence in incident light. The chatoyance is directly connected with the thin films seen in the photomicrograph. These films are not crystal inclusions. Typical schiller *effects* produced from a striking "endoblastic" *structure*.

Both the pyroxene, Figure 4, in the pyroxenite from Puerto Rico, previously referred to, and the pyroxene, Figure 5, in an olivine gabbro from Minnesota, contain small irregular areas exhibiting films along parting planes which appear black in the photomicrographs and thicker than they really are, because the sections are somewhat oblique to the planes along which the "films" are distributed. These are not magnetite inclusions; they are thin brownish films, which give distinct, though feeble, color reflections in incident light from properly oriented grains in the sections.

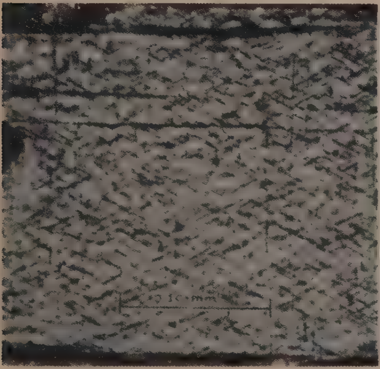

FIG. 7. Hypersthene in the complex emery rock of the Cortlandt Series, ordinary light; the scale is 0.10 mm. The inclusions are extremely minute crystal needles oriented in three directions, and brilliantly iridescent in reflected light, giving a typical schiller *effect*. The rock is metamorphic, and so far as the writer is aware this, and the biotite illustrated in Fig. 8, are the only recorded examples of schiller effects in minerals of metamorphic rocks. The *structure* in the hypersthene is "endoblastic."

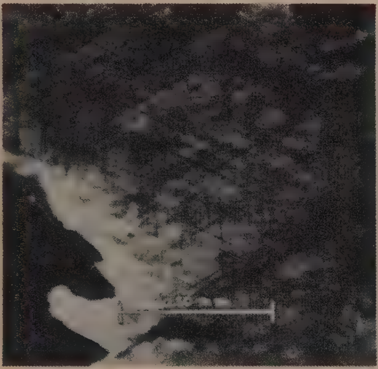

FIG. 8. Biotite in the same complex emery rock in which the hypersthene, illustrated in Fig. 7 occurs, ordinary light; the scale is 0.10 mm. The crystal lies with the base parallel to the surface of the section; it is dark colored and shows strong absorption, hence difficult to photograph. The thin needles, oriented in three directions, exhibit brilliant iridescence in reflected light. This structure in biotite has been called "sagenite structure," but the term "endoblastic" is also appropriate.

According to Judd (15), schillerization in pyroxenes is due to alteration along solution planes with the production of negative cavities filled with the products of decomposition. Neither the hypersthene nor the pyroxene in the rocks mentioned above are in the least altered. Some of the pyroxene in the pyroxenite from Puerto Rico has been converted into hornblende, but the hornblende derived from the pyroxene is not iridescent; whereas the grains of unaltered pyroxene that contain "films" along parting planes exhibit some chatoyance, even if slight, provided they are favorably oriented in the sections. Alteration, therefore, does not seem to be a necessary factor.

The phenomenon is not confined to minerals of the igneous rocks, for some of the hypersthene, and even an occasional biotite flake, in the complex emery rock of the Cortlandt Series, react in the same way under appropriate conditions of illumination. According to Rogers (20) the emery rock is a product formed by the assimilation of blocks of Manhattan schist in the invading norite of the Cortlandt Series; Gillson and Kania (9), however, concluded that the emery deposits are

> . . . contact metamorphic in origin, and were formed by either gaseous or liquid emanations from the magma reservoir, which passed upward through the already solid border of the igneous mass, ("melanorite" according to the authors) and into the schists (Manhattan schist), depositing the ore minerals in both the endomorphic and exomorphic zones.

Whether the emery rock is a syntectic product, as postulated by Rogers, or a hydrothermal contact metamorphic product, as assumed by Gillson and Kania, the mineral ensemble in it is characteristically metamorphic; the hypersthene is intimately associated with sillimanite, spinel, corundum, magnetite, quartz, cordierite, garnet, enstatite, andesine, calcite, biotite, and other related, but less abundant components. The hypersthene carries inclusions of both intersecting needles (see Figure 7) with a three-way orientation, and dark, wine-red, rectangular scales or "films," so thin that they are superposed in two or more layers within the thin section. Both needles and "films" are iridescent in oblique incident light in favorably oriented grains. The needles are crystal inclusions, but the nature of the "films" is not determinable in thin section.

In another section[6] of the same material occasional reddish-brown flakes of biotite lying in the section with their bases parallel to the surface of it contain three sets of intersecting, hair-like inclusions, presumably rutile, illustrated in Figure 8, which are brilliantly iridescent in incident light. This is the only example of the schiller effect in biotite that has come to the attention of the writer.

In all of the examples observed iridescence is confined strictly to the inclusions, whether they be needles, rods, plates or "films." Those portions of the host mineral free of inclusions are not iridescent at all; at least under the conditions of illumination previously mentioned. Iridescence seems to be independent of the *kind* of inclusions; that is, there is no single, specific sort of inclusion that alone displays the phenomenon to the exclusion of all other kinds. Consequently the writer believes that the term "schiller *structure*" is a misnomer, for there is no single specific structure responsible for the effect, which seems to be dependent rather on the minute size and thinness of the included matter than on the substance of it. If the inclusions are too large or too thick, it apparently matters not at all what their orientation may be; they are then not iridescent. Moreover, it seems certain, from the work of previous investigators, that some minerals, notably certain of the feldspars, display iridescence although there are no inclusions in them; the color effect in such cases being due to reflection of light from sub-microscopic planes. The tentative suggestion is made, therefore, that the term "schiller" be restricted to the iridescence displayed by minerals, whether the sheen or chatoyance is caused by reflection of light from either inclusions or planes. For minute *inclusion structures*, especially those structures formed by the separation of substances from solid solution in rock forming minerals, no matter whether iridescence is produced by them or not, the writer ventures to suggest the term "endoblastic"; from "endon," within, and "blastos," a sprout or shoot. "Blast" has long been used both as a suffix and prefix in metamorphic terminology, but the usage intended here refers to the microcrystallization or growth *within* a solid crystal.

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[6] The sections were cut from the lighter fractions obtained during a mill-run of the emery rock.

Endoblastic structures, used in this sense, are those minute structures produced in individual host crystals, either by the separation from solid solution of oriented and usually intersecting sets of crystal needles, plates or rods, or oriented "films" and roughly euhedral "negative" cavities, filled or empty. The term does not apply to larger inclusions in crystals, for which the expression poikilitic has long been used and which may have been formed in other ways.

LIST OF REFERENCES

1. Agar, W. M., The Hodges Nickel Prospect, Torrington, Connecticut: *Am. Jour. Sci.*, (5) vol. **19**, pp. 185–194, 1930.
———, Thermally Metamorphosed Diorite near Brookfield, Connecticut: *Am. Jour. Sci.*, (5) vol. **28**, No. 168, pp. 401–411, 1934.

2. Andersen, O., On Aventurine Feldspar: *Am. Jour. Sci.*, (4) vol. **40**, pp. 351–398, 1915.
3. Bancroft, J. Austen, Geology of the Coast and Islands between the Strait of Georgia and Queen Charlotte Sound, B.C.: *Mem.* **23**, *Can. Dept. Mines*, p. 97, 1913.
4. Bøggild, O. B., On the Labradorization of Feldspars: *Det. Kgl. Danske Videnskab. Selskab, Math. Fys. Medd.*, vol. **6**, 3, pp. 1–79, 1924.
5. Brewster, David, On Certain New Phenomena of Color in Laborador Felspar, with Observations on the Nature and Cause of its Changeable Tints: *Trans. Royal Soc. Edinb.*, vol. **11**, pp. 322–331, 1831.
6. Cathrein, A., Ueber die Hornblende von Roda: *Zeits. Kryst. und Min.*, vol. **13**, pp. 9–14, 1887.
7. Colony, R. J., and Meyerhoff, H. A., The Magnetite Deposits near Humacao. Puerto Rico: *Tech. Paper* No. **587**, *Am. Inst. Min. & Met. Engs.*, 1935.
8. Des Cloiseau, A., Manuel de Mineralogie: vol. **1**, pp. 46, 109, 113, 1862.
9. Gillson, Joseph L., and Kania, Joseph E. A., Genesis of the Emery Deposits near Peekskill, New York: *Econ. Geol.*, vol. **25**, 5, pp. 506–527, 1930.
10. Hagge, R., Mikroskopische Untersuchung über Gabbro und verwandte Gesteine: Kiel, **1871.**
11. Haidinger, W., Note über den metallähnlichen Schiller des Hypersthens: *Pogg. Annal.*, vol. **76**, pp. 294–297, 1849.
12. Haüy, A., Traite de Mineralogie, II, 2nd Ed., **1822.**
13. Hobbs, W. H., On Two New Occurrences of the "Cortlandt Series" of Rocks within the State of Connecticut: *Fest. von Harry Rosenbusch*, Stuttgart, pp. 25–48 **1906.**
14. Hutton, F. W., On a Hornblende-Biotite Rock from Dusky Sound, New Zealand: *Quart. Jour. Geol. Soc.*, vol. **44**, pp. 745–746, 1888.
15. Judd, J. W., On the Tertiary and Older Peridotites of Scotland: *Quar. Jour. Geol. Soc.*, vol. **41**, pp. 354–418, 1885.
16. Kosmann, B., Über das Schillern und den Dichroismus des Hypersthens: *Neues Jahrb. für Min.* etc., pp. 532–547, **1869.**
17. Nordenskjöld, Nils, Untersuchung einiger neuen Phänomene beim Farbenspiel des Labradors: *Pogg. Annal.*, vol. **19**, pp. 179–190, 1830. Translated into German by Senff.
18. Parsons, A. L., Iridescent Color in Peristerite: *Am. Mineral.*, vol. **15**, 3, pp. 85–97, 1930.
19. Reusch, E., Über das Schillern gewisser Krystalle: *Pogg. Annal.*, vol. **116** (192), pp. 392–412, 1862; Vol. **120** (196), pp. 95–118, 1863.
20. Rogers, G. S., Geology of the Cortlandt Series and Its Emery Deposits: *Annals N. Y. Acad. Sci.*, vol. **21**, pp. 11–86, 1911.
21. Rose, G., Ueber die Gabbroformation von Neurode in Schlesien: *Zeits. der Deuts. geol. Gesells.*, vol. **19**, pp. 270–296, 1867.
22. Rosenbusch, H., Mikroskopische Physiographie der Mineralien und Gesteine: Wülfing and Mügge, p. 531, **1927.**
23. Scheerer, T., Untersuchung des Sonnensteins: *Pogg. Annals.*, vol. **64**, pp. 153–162, 1845.

   ———, Mikroskopische Untersuchung verschiedener Mineralien: *Pogg. Annal.*, vol. **64**, pp. 162–169, 1845.

24. Senff, J., Der finnländische Labrador: *Pogg. Annal.*, vol. **17**, pp. 352–357, 1829.
25. Streng, A., Über den Gabbro und den sogenannten Schillerfels des Harzes: *Neues. Jahrb.*, pp. 513–556, **1862.**
26. Tertsch, H., Optische Untersuchung von Hornblenden und Titanit aus Essexit von Montreal: *Tschermak's Min. und Pet. Mittheil.*, vol. **25**, pp. 457–482, 1906–7.
27. Vogelsang, H., Sur le labradorite coloré de la Côte du Labrador: *Extrait des Archives Neerlandaises*, Tome **3**, pp. 1–32, 1868.
28. von Bonsdorff, *Neues Jahrb.*, p. 681, **1838**, abstract.
29. von Hessel, J. F. Ch., Beschreibung eines neuen Farbenwandlungsappartes, der dazu gehörigen Objecte und der damit anzustellenden zum Theil neuen Versuche: *Pogg. Annal.*, vol. **79**, pp. 442–454, 1850.
30. von Raumer, Karl, Das Gebirge Nieder-Schlesiens der Grafschaft Glatz und einer Theils von Böhmen und Ober-Lausitz: Univ. Breslau, Berlin, p. 40, 1819.
31. Williams, G. H., The Peridotites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y.: *Am. Jour. Sci.*, (3), vol. **31**, pp. 26–41, 1886.
    ———, Norites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y.: *Am. Jour. Sci.* (3), vol. **33**, pp. 135–144; 191–199, 1887.
    ———, The Gabbros and Diorites of the "Cortlandt Series" on the Hudson River near Peekskill, N. Y.: *Am. Jour. Sci.*, (3) vol. **35**, pp. 438–448, 1888.
32. Zirkel, Ferdinand, Die Mikroskopische beschaffenheit der Mineralien und Gesteine; pp. 79–85; 184–186, **1873.**
    ———, *Zeits. der deuts. geol. Gesells.*, vol. **23**, 1871.

A TABULATION OF CRYSTAL FORMS AND DISCUSSION OF FORM-NAMES

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The writer presents herewith a tabulation of the names of crystal forms, all of which are based upon the geometrical method of Fedorov. This paper also affords an occasion to discuss the standardization of names of forms as proposed by members of the Fedorov Institute of Leningrad[1] and by Wherry.[2] Let it be emphasized that no new names are introduced by the writer. After a perusal of a compilation of the various form-names used by crystallographers for the past hundred years or so, such as is being made by the writer, one would be bold indeed to propose any new names. For example, more than 30 different names have been used for the $\{hkl\}$ form in the ditetragonal dipyramidal class. Names in great sufficiency are available; it is only necessary to choose the best ones for our purpose.

There are two general methods of naming forms. One method is to name the form according to the number and shape of faces; the other method is to name the form according to the position of the constituent faces with respect to the axes of reference.

The first method is used universally for crystal forms of the isometric, tetragonal, and hexagonal systems, but for forms of the other three systems both methods are employed. The practice of naming forms according to the position of faces relative to the axes of reference in the orthorhombic, monoclinic, and triclinic systems is a glaring inconsistency in the opinion of the writer.

FEDOROV'S PLAN OF NAMING FORMS

Fedorov[3] was the first to propose that the names of crystal forms in all systems should depend upon the intrinsic character of the form and not upon the attitude of the faces with respect to axes of reference. Fedorov's method was soon adopted by Groth[4] and by Liebisch[5] and later by other crystallographers, but for some unexplained reason it has not received the support that it deserves.

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[1] See Boldyrev, *Zeit. f. Kryst.*, vol. **62**, pp. 145–150, 1925.

[2] *Am. Mineral.*, vol. **15**, pp. 418–427, 1930.

[3] *Zeit. f. Kryst.*, vol. **21**, pp. 574–600, 1893.

[4] *Physikalische Krystallographie*, 3er Auflage, Leipzig, 1895.

[5] *Grundriss der Physikalischen Krystallographie*, Leipzig, 1896.

Fedorov was a geometer of some note as well as a crystallographer and his plan of naming forms according to their geometry merits careful consideration.

Let us contrast Fedorov's names of forms with the older names used. In the rhombic dipyramidal class, it was formerly the custom to speak of the $\{hk0\}$ form as a rhombic prism and of the $\{h0l\}$ and $\{0kl\}$ forms as domes. Fedorov calls all three of them rhombic prisms. The placing of one of them, $\{hk0\}$, in a vertical position parallel to the c-axis does not change the character of the other two. They are still rhombic prisms and should be called such. Fedorov distinguished the three forms mentioned by the addition of a phrase such as "of the first kind," but the writer prefers simply to distinguish them by the appropriate Miller type symbol. These three forms on a crystal or model are noted as rhombic prisms when they are first encountered. As soon as the crystal is oriented, the type or literal symbols may be assigned to the forms.

The term "dome" used by many crystallographers for the $\{0kl\}$ and $\{h0l\}$ forms of the rhombic dipyramidal class should then be reserved for the two-faced forms astride a plane of symmetry, which are limited to the rhombic pyramidal and domatic classes.

In the holosymmetric class of the monoclinic system, the general form $\{hkl\}$ is not a "hemi-pyramid" because it intersects all three axes of reference. Here $\{hkl\}$ and $\{hkl\}$ together do not form a pyramid. Geometrically it is a rhombic prism and should be called such. In a monoclinic crystal of unknown identity, $\{hkl\}$, $\{hk0\}$, and $\{0kl\}$ may be interchanged in position. The character of these three forms is the same regardless of orientation. Why should the form selected for $\{hk0\}$ be called a rhombic prism any more than the others? A similar argument may be used for the $\{h0l\}$ form. Why should $\{h0l\}$ be called a hemi-dome? It is a pinakoid because it consists of two opposite parallel faces. It might be selected as the $\{001\}$ or $\{100\}$ form. The forms $\{100\}$, $\{h0l\}$, $\{001\}$, and $\{h0l\}$ are all pinakoids in this class. In order to distinguish them it is only necessary to use the Miller type symbols.

In the pinakoidal class of the triclinic system why should $\{hkl\}$ be called a "tetra-pyramid," when it is a form that consists of two opposite parallel faces and is obviously a pinakoid? Why should $\{hk0\}$ be named a "hemi-prism" and $\{0kl\}$ and $\{h0l\}$, "hemi-domes" when they are all pinakoids? It may be urged that the older names should be used in order to distinguish the various forms, but the distinctions in the older names cannot be made until the crystal is oriented. When oriented, it is just as easy to use the type symbols.

Two curious attempts to combine the supposed advantages of the two methods of nomenclature have come to the notice of the writer. Tutton,[6] for example, uses the term "bipyramidal pinakoid" for the $\{hkl\}$ form in the pinakoidal class and Wherry[7] uses a similar term "pyramidopinakoid" for the same form. For the $\{0kl\}$ and $\{h0l\}$ forms of the rhombic dipyramidal class they use respectively "brachydomal prism," "macrodomal prism" and "brachydomoprism," "macrodomoprism." In the opinion of the writer these names are even less satisfactory than the older names they are intended to supplant. Their intelligent use would demand a knowledge of the history of geometrical crystallography which the student cannot be expected to possess. It is doubtful whether they will ever gain wide acceptance.

Some of the critics of the Fedorov method will doubtless contend that the older names mentioned have priority over Fedorov's names. Let us look into the historical record. The term "horizontale Prismen" was used by Mohs[8] as early as 1822. In this usage he was followed by Naumann (1826), Hartmann (1829), G. Rose (1833), Miller (1845), Kenngott (1846), and J. D. Dana (1850). "Prisma transversum" was used by Hessel (1830) with the same meaning. "Dome" in the older sense, on the other hand, was first introduced into crystallographic literature by Breithaupt in 1836.

G. Rose in 1833 and Hartmann in 1843 used the term "Prismen rhombische schiefe" for the $\{hkl\}$ form in the prismatic class of the monoclinic system, but Naumann's (1826) name, "hemipyramid," was taken up by Breithaupt (1836), Hausmann (1847), Kopp (1849), and J. D. Dana (1850) and came into general use instead of the more logical term, prism.

Fedorov and Groth used the term bipyramid for a double-ended form. The equivalent of this term has priority over the term "pyramid" which is used by some crystallographers even at the present time. Weiss (1818), Grassmann (1829), Kupffer (1831), and Frankenheim (1842) used the term "Doppelpyramiden." Hessel (1830) used "Dipyramis" for the double-ended form. The usage of "pyramid" for the double-ended form is due largely to Naumann (1841). In geometry a pyramid is a one-ended form. This is a geometrical term and crystallographers should not change the essential meaning of it.

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[6] *Crystallography and Practical Crystal Measurement*, 1st ed., p. 284, London, 1911.

[7] *Loc. cit.*, p. 427.

[8] *Grundriss der Mineralogie*, 1er Theil, p. 111, Dresden, 1812.

The illogical nomenclature of the older form-names is due in part to the fact that only four crystal systems were recognized at first by Weiss and Mohs. For some years after this, monoclinic and triclinic crystals were considered to be hemihedral forms of orthorhombic crystals. The name hemi-pyramid for $\{hkl\}$ in the monoclinic system would seem a natural name for a hemihedral form of the $\{hkl\}$ pyramid in the orthorhombic system. And similarly $\{hkl\}$ of the triclinic system might be regarded as a tetartohedral form of the $\{hkl\}$ pyramid of the orthorhombic system and so would be called a tetrapyramid.

Inadequacy of the Older Form-Names

It should be pointed out that the older names were perhaps adequate a half century ago when only part of the crystal classes were well known. During the past few decades nearly all the crystal classes have become so well understood that we need an adequate nomenclature suitable for all possible crystal forms, known as well as unknown. It is my conviction that this is admirably supplied by the Fedorov method. Although trained in the older method, as soon as I encountered the Fedorov nomenclature in a book by the late Professor Alfred J. Moses,[9] I was convinced of its value. Since 1905 I have consistently used Fedorov's names of forms both with elementary and advanced students.

The apparent simplicity of the older nomenclature displayed in some textbooks is due to the fact that the less important crystal classes are inadequately treated.

Tabulation of the Forty-Eight Possible Crystal Forms

Now we come to the tabulation itself. The various forms are listed in ten horizontal divisions giving the number of faces in the forms. These numbers are 1, 2, 3, 4, 6, 8, 12, 16, 24, and 48. There are two vertical columns, one on the left with open forms and the other on the right with closed forms. In all, there are 18 open forms and 30 closed forms. Of the closed forms, 15 are isometric. Invariable forms or those in which the interfacial angles are always the same,

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[9] *Characters of Crystals*, New York, 1899.

I. Tabulation of the Forty-Eight Possible Crystal Forms

No. of faces	Open Forms		Closed Forms	
1 face	Pedion	GL		
2 faces	*Pinakoid	GL		
	Sphenoid	GL		
	Dome	GL		
3 faces	*Trigonal Prism	L		
	Trigonal Pyramid	GL		
4 faces	Rhombic Prism	GL	Rhombic Disphenoid	G
	Rhombic Pyramid	G	Tetragonal Disphenoid	GL
	*Tetragonal Prism	L	*Tetrahedron	L
	Tetragonal Pyramid	GL		
6 faces	*Hexagonal Prism	L	*Cube	L
	Hexagonal Pyramid	GL	Rhombohedron	GL
	Ditrigonal Prism	L	Trigonal Dipyramid	GL
	Ditrigonal Pyramid	GL	Trigonal Trapezohedron	G
8 faces	Ditetragonal Prism	L	*Octahedron	L
	Ditetragonal Pyramid	GL	Rhombic Dipyramid	G
			Tetragonal Dipyramid	GL
			Tetragonal Scalenohedron	G
			Tetragonal Trapezohedron	G
12 faces	Dihexagonal Prism	L	Ditrigonal Dipyramid	G
	Dihexagonal Pyramid	G	Hexagonal Dipyramid	G
			Hexagonal Scalenohedron	G
			Hexagonal Trapezohedron	G
			*Dodecahedron	L
			Pyritohedron	L
			Tristetrahedron	L
			Deltohedron	L
			Tetartoid	G
16 faces			Ditetragonal Dipyramid	G
24 faces			Dihexagonal Dipyramid	G
			Trapezohedron	L
			Trisoctahedron	L
			Tetrahexahedron	L
			Hextetrahedron	G
			Diploid	G
			Gyroid	G
48 faces			Hexoctahedron	G

(*=invariable forms; the others are variable. G=general form, L=limit form) are marked with an asterisk. The unmarked forms have variable interfacial angles. The tetragonal prism, for example, is an invariable form since the angle $(110:1\bar{1}0)$ or $(hk0:\bar{k}h0)$ is always 90°; the rhombic prism, on the other hand, is variable.

There are 48 kinds of forms possible. Of these, all but four have actually been found on crystals. The four forms not yet discovered are the ditetragonal pyramid, the hexagonal trapezohedron, the dihexagonal pyramid, and the gyroid.[10] The tetragonal trapezohedron was first found as late as 1907 (on methyl ammonium iodid), and the ditrigonal dipyramid as late as 1909 (on benitoite).

GENERAL FORMS

Of the 48 forms, 32 are general forms and may be derived directly from the symmetry by a well-known procedure. A list of these general forms is given. This list gives the name of the general form, the number of faces in the form, and the symmetry from which the general form is derived. The symbols for the symmetry elements are discussed in a paper by the writer.[11] The symbol $Æ_n$ stands for a rotatory-reflection axis and $\mathcal{A}_n$ for a rotatory-inversion axis. According to the writer's method of deriving each face of the general form directly from the initial face,[12] it is necessary to employ both kinds of composite axes of symmetry. The parentheses around a symmetry element indicates that the particular element is included in another symmetry element listed. For example, (C) is included in $Æ_6$ or $4Æ_6$ and (P) is included in $\mathcal{A}_6$. The brackets indicate that one or more of the operations of the symmetry element enclosed is also included in another symmetry element listed. For example, in classes 25 and 27, the elements, A_6, $(Æ_6)$, and $(\mathcal{A}_6)$ have rotations of 120° and 240° in common.

LIMIT FORMS

The other 16 forms $(48-32=16)$ are limit forms (see Table IIb), the faces of which have a special position with respect to *symmetry directions*.[13] These forms are called limit forms since they may be derived from general forms by decreasing certain interfacial angles,

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[10] The apparent gyroid found on cuprite is probably due to symmetrical malformation, for etch-figures prove that cuprite belongs to the hexoctahedral class.

[11] *Am. Mineral.*, vol. **13**, pp. 571–577, 1928.

[12] *Proc. Amer. Acad. Arts and Sciences*, vol. **61**, p. 162, 1926.

[13] I use this term for directions fixed by symmetry which are axes of symmetry or lines normal to planes of symmetry.

IIa. TABLE OF GENERAL FORMS

General Form	Faces	Symmetry
Pedion	1	
Pinakoid	2	C
Dome	2	P
Sphenoid	2	A_2
Trigonal Pyramid	3	A_3
Tetragonal Pyramid	4	A_4
Hexagonal Pyramid	6	A_6
Rhombic Pyramid	4	$A_2 \cdot 2P$
Ditrigonal Pyramid	6	$A_3 \cdot 3P$
Ditetragonal Pyramid	8	$A_4 \cdot 4P$
Dihexagonal Pyramid	12	$A_6 \cdot 6P$
Rhombic Prism	4	$A_2 \cdot P \cdot C$
Trigonal Dipyramid	6	$\text{CA}_6 \cdot (P)$
Tetragonal Dipyramid	8	$A_4 \cdot [\text{Æ}_4] \cdot P \cdot C$
Hexagonal Dipyramid	12	$A_6 \cdot [\text{Æ}_6] \cdot [\text{CA}_6] \cdot (P) \cdot (C)$
Rhombic Disphenoid	4	$A_2 \cdot 2A_2$
Trigonal Trapezohedron	6	$A_3 \cdot 3A_2$
Tetragonal Trapezohedron	8	$A_4 \cdot 4A_2$
Hexagonal Trapezohedron	12	$A_6 \cdot 6A_2$
Rhombic Dipyramid	8	$A_2 \cdot 2A_2 \cdot 3P \cdot C$
Ditrigonal Dipyramid	12	$\text{CA}_6 \cdot (P) \cdot 3A_2 \cdot 3P$
Ditetragonal Dipyramid	16	$A_4 \cdot [\text{Æ}_4] \cdot 4A_2 \cdot 5P \cdot C$
Dihexagonal Dipyramid	24	$A_6 \cdot [\text{Æ}_6] \cdot [\text{CA}_6] \cdot 6A_2 \cdot 6P \cdot (P) \cdot (C)$
Tetragonal Disphenoid	4	$\text{Æ}_4 \cdot$
Rhombohedron	6	$\text{Æ}_6 \cdot (C)$
Tetragonal Scalenohedron	8	$\text{Æ}_4 \cdot 2A_2 \cdot 2P$
Hexagonal Scalenohedron	12	$\text{Æ}_6 \cdot 3A_2 \cdot 3P \cdot (C)$
Tetartoid	12	$4A_3 \cdot 3A_2$
Gyroid	24	$3A_4 \cdot 4A_3 \cdot 6A_2$
Diploid	24	$4\text{Æ}_6 \cdot 3A_2 \cdot 3P \cdot (C)$
Hextetrahedron	24	$4A_3 \cdot 3\text{Æ}_4 \cdot 6P$
Hexoctahedron	48	$3A_4 \cdot [3\text{Æ}_4] \cdot 4\text{Æ}_6 \cdot 6A_2 \cdot 9P \cdot (C)$

IIb. TABLE OF LIMIT FORMS

Prisms	Trigonal Prism	Limit Form of Trigonal Dipyramid
	Tetragonal Prism	Limit Form of Tetragonal Dipyramid
	Hexagonal Prism	Limit Form of Hexagonal Dipyramid
	Ditrigonal Prism	Limit Form of Ditrigonal Dipyramid
	Ditetragonal Prism	Limit Form of Ditetragonal Dipyramid
	Dihexagonal Prism	Limit Form of Dihexagonal Dipyramid
Isometric Forms	Trisoctahedron	Limit Form of Hexoctahedron
	Trapezohedron	Limit Form of Hexoctahedron
	Tetrahexahedron	Limit Form of Hexoctahedron
	Deltohedron	Limit Form of Hextetrahedron
	Tristetrahedron	Limit Form of Hextetrahedron
	Pyritohedron	Limit Form of Diploid
	Dodecahedron	Limit Form of Trisoctahedron or Tetrahexahedron
	Cube	Limit Form of Trapezohedron or Tetrahexahedron
	Octahedron	Limit Form of Trapezohedron or Trisoctahedron
	Tetrahedron	Limit Form of Deltohedron or Tristetrahedron

thus obtaining other general forms until they finally approach the desired form as a limit. For example, starting with the general form {211} in the ditetragonal dipyramidal class, we may decrease *per saltum*, the angle $(hkl{:}hk\bar{l})$ thus obtaining the forms {632}, {421}, {631}, {841}, {10.5.1}, etc., with a constantly increasing value of k/l. As the angle mentioned becomes smaller and smaller it approaches 0°, and we finally obtain the ditetragonal prism {210}, which is said to be the limit, or limiting, form of the ditetragonal dipyramid {211}.

An excellent example of the limit forms in the hexoctahedral class is shown in the frontispiece of Williams' textbook.[14]

Six of the limit forms are prisms; the other prism (rhombic prism) is the general form in the prismatic class of the monoclinic system. The other ten limit forms are isometric. Of these, the last four listed cannot be derived directly from general forms. They are limit forms of other limit forms as will be noted.

It is thus possible to derive all of the 48 forms either directly or indirectly from the symmetry without recourse to merohedrism.

Some of the forms are general forms in a particular class and also limit forms either in the same class or another class. For example, the rhombic prism is a general form in the prismatic class and limit forms $\{hk0\}$ and $\{0kl\}$ in the same class and also limit forms $\{hk0\}$, $\{h0l\}$, and $\{0kl\}$ in the rhombic dipyramidal class.

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[14] *Elements of Crystallography*, 3rd ed., New York, 1892.

Remarks on Some of Wherry's Form-Names

Before I comment on the individual forms, some general remarks on Wherry's names of forms may be made, especially since he has invited criticism. Wherry objects to form-names that indicate the *shape* of faces. His objection is based upon . . . "the extreme rarity of crystals bounded by single forms (except of course (100) and (111)) . . . ."[15] He advocates names that indicate the *number* of faces present. This plan has been followed to some extent in names in general use, but I believe it is a mistake to push the matter to its logical conclusion. There are no less than ten distinct 12-faced forms; to call more than one of these a dodecahedron is to create confusion. As to names based upon shapes of crystals, I do not believe that Wherry's objections are very serious. In the study of geometrical crystallography, models of simple forms are practically always available. The naming of minor forms on models or crystals is a valuable exercise; it helps develop the imagination and this is one of the principal benefits of the study of geometrical crystallography. An objection can also be raised to using names based upon the number of faces. In many cases the total theoretical number of faces of a form is not present on a crystal; this point has been emphasized by Victor Goldschmidt. The fact that some names are based upon the shape of faces and some upon the number of faces is not a very serious matter. In any event the nomenclature is too well established to insist upon a strictly consistent and logical set of names.

Comments on the Names of Forms

Pedion, introduced by Groth[16] in 1895 and adopted by Lewis[17] is a very useful term for the one-faced form. "Plane" or "face" has been used to designate such a form, but there is need of a definite technical word to replace these terms which have a more general meaning. Pedion is better than Fedorov's name "hemi-pinakoid." It is shorter and simpler than "monohedron" which was proposed by the Fedorov Institute[18] and also recommended by Wherry.

[15] *Loc. cit.*, p. 418.

[16] *Loc. cit.*, p. 337.

[17] *A Treatise on Crystallography*, p. 148, London, 1899.

[18] Boldyrev, *loc. cit.*, p. 146.

The term pinakoid is used by the older crystallographers for forms with faces that are parallel to two axes of reference and cut a third, except for forms in the isometric and tetragonal systems. Fedorov expanded it to include all forms with two opposite parallel faces in whatever system they are found and whatever their position on the crystal may be.

The terms sphenoid and dome have been combined into the single term "dihedron" by the members of the Fedorov Institute. This is, in my opinion, a backward step. Altho both of these are non-parallel two-faced forms, one of them is the result of the operation of rotation and the other of the operation of reflection. It is important to distinguish these two forms so as to have distinctive names for the general forms of the merosymmetric classes of the monoclinic system. Wherry also uses "dihedron" as a substitute for dome.

As to the seven kinds of prisms, there is little to be said except to protest against Wherry's proposal to use "duploprism," instead of ditetragonal and dihexagonal prisms. Altho Wherry's term is shorter, it can only be used in connection with the particular system, so we need qualifying terms such as ditetragonal and dihexagonal. The same objection can be urged against Wherry's terms "normo-prism" and "chordo-prism." The names of forms according to Fedorov's plan are independent of both crystal systems and axes of reference and this is very desirable.

I can see no particular advantage in Wherry's "trigonoprism" over trigonal prism. Trigonal is analogous to tetragonal and hexagonal.

The names pyramid and dipyramid are much to be preferred to the alternative terms, "hemimorphic pyramid" and "pyramid." The Russian crystallographer Vulf (G. Wulff) not many years ago proposed that dipyramid be used instead of bipyramid and he has generally been followed by advocates of the Fedorov plan. It is rather inconsistent to use such a term as *di*trigonal *bi*pyramid (*di* is Greek and *bi* is Latin) since pyramid is derived from the Greek.

The general form in the rhombic disphenoidal class and the tetragonal disphenoidal class is often called a "sphenoid" but since these forms are double-ended, this term is not satisfactory. We need another term such as disphenoid or sphenohedron; between these two there is little choice except that disphenoid has been used more often in recent years. The Fedorov Institute proposes to call these forms rhombic tetrahedron and tetragonal tetrahedron, but it seems better to restrict tetrahedron entirely to the regular tetrahedron.

Rhombohedron is used almost universally for the six-faced form with a rotatory-reflection axis. I am surprised to learn that Wherry would like to substitute such a term as "ditrihedron" for it. Probably no other form name has fewer synonyms than rhombohedron; this in itself is an excellent argument for retaining the name.

We have two scalenohedrons, one variously distinguished as tetragonal, quadratic, ditetragonal, or didigonal; the other as hexagonal, dihexagonal, or ditrigonal. I prefer to choose the simplest of these terms which are tetragonal and hexagonal. Their plan views are respectively bounded by a square and a regular hexagon. Both terms tetragonal scalenohedron and hexagonal scalenohedron were used by Naumann in 1854. Wherry's substitutes for these, which are "duplo-disphenoid" and "duplo-ditrihedron," have not very much to recommend them.

There are three trapezohedrons, distinguished as trigonal, tetragonal, and hexagonal. These names have very wide usage and are probably as good as any that could be devised. They are recommended by the Fedorov Institute. Wherry however proposes to call them respectively "gyro-trigonodipyramid," "gyro-dipyramid," and "gyro-dipyramid." The last term can only be used in connection with a particular crystal system. It is not likely that these terms will come into general use.

Finally we come to the fifteen isometric forms. Of these, J. D. Dana's (1850) hexoctahedron is preferred to Miller's (1839) hexakisoctahedron. Similarly, hextetrahedron, tetrahexahedron, and trisoctahedron are better than hexakistetrahedron, tetrakishexahedron, and triakisoctahedron, respectively. The Greek syllable -*kis*- (times) may be omitted in order to simplify the words which are complex enough even at their best.

The only difficulty with trapezohedron is its possible confusion with the trigonal, tetragonal, and hexagonal trapezohedrons. Trapezohedron without a qualifying term signifies the one in the isometric system. Icositetrahedron is too long and besides there are five other isometric forms with 24 faces. Tetragonal trisoctahedron is also too long.

In the name pyritohedron we have another difficulty. It is the sole survivor of an old custom of naming crystal forms after the names of minerals. Formerly leucitoid or leucitohedron was used for the trapezohedron, fluoroid for the tetrahexahedron, galenoid for the trisoctahedron, adamantoid (from diamond) for the hexoctahedron, granitoid for the dodecahedron, cuproid (from copper) for tristetrahedron, borazitoid for the hextetrahedron, quartzoid for the hexagonal dipyramid, berylloid for the dihexagonal dipyramid, and zirkonoid for the ditetragonal dipyramid. This custom fortunately has been discontinued. One objection to it is that the mineral that furnishes the name may prove to have symmetry different from the one that was first assigned to it. The other names for the pyritohedron are not satisfactory. It is not, strictly speaking, a pentagonal dodecahedron, for the faces are not regular pentagons. "Dyakishexahedron" and "dihexahedron" are not well suited names for this form. There is nothing in the appearance of the form to suggest a cube, which is not the case with the tetrahexahedron. "Dihexahedron" was formerly a widely used term for the hexagonal dipyramid. For the want of a better name, the term pyritohedron is used.

Deltohedron was introduced by Haidinger in 1845 for the $\{hkl\}$ form in the hextetrahedral and tetartoidal classes. It was adopted by J. D. Dana and replaced deltoid dodecahedron. Another synonym of it is tetragonal tristetrahedron which is too long. Wherry calls it "hemicositetrahedron," which is equally bad.

Haidinger's term diploid is probably the best one for the $\{hkl\}$ form in the diploidal class of the isometric system. Wherry says " . . . the complex expressions often used for the $\{hkl\}$ form may be simplified to *didodecahedron*." But what name for this form could be simpler than diploid?

Haidinger's (1845) term gyroid seems better than gyrohedron (Quenstedt, 1854), plagihedron (Haidinger used this for the trigonal trapezohedron), pentagonal icositetrahedron, pentagontrioctahedron (Fedorov Institute), or gyricositetrahedron (Wherry). Since gyroid is the only form name in the list in which "gyro" appears, it is distinctive.

Tetartoid introduced by Haidinger in 1845 is the simplest name for the general form of the tetartoidal class. It is better than tetartohedron, "gyrotritetrahedron" (Wherry), or tetrahedral-pentagonal-dodecahedron. Tetartoid is the only name in the entire list that shows the influence of the concept of merohedrism.

It is a question whether dodecahedron or rhomb-dodecahedron (or rhombododecahedron) should be used for {110} in the isometric system. If dodecahedron is used, there is possible confusion with the non-crystallographic regular dodecahedron of geometry, but on the other hand, it is the only form-name in the entire list with dodecahedron in it. For this reason dodecahedron is retained.

Octahedron is now used universally for the {111} form and such terms as quadratic octahedron and rhombic octahedron have fortunately almost disappeared from crystallographic literature. Cube seems better to me than hexahedron. There is general agreement on the term tetrahedron.

With the possible exceptions of trapezohedron and pyritohedron the form-names given in the list are believed to be entirely satisfactory. They are comparatively simple, consistent, and free from ambiguity. I do not mean to say that if one were free to choose his own terms untrammeled by former usage he could not do better. But for the sake of continuity with the past it seems advisable to use well-established terms, tho not necessarily those with priority.

What I urge especially is the plan of Fedorov, adopted by Groth, of naming forms according to their geometry.

NAMES OF SYMMETRY CLASSES

The fact that the general form is distinctive for each symmetry class suggests, as it did to Groth, that the names of general forms might be used as class names. This, in my opinion, is the most satisfactory method of designating the crystal classes. The names are entirely free from ambiguity; it is doubtful whether this is true of any other method.

Since the crystal classes are derived from the various types of symmetry without regard to crystal systems, this fact should be reflected in the class names. This is only true, I believe, of class names based upon the names of general forms.

The class names used by Miers[19] and adopted by Phillips[20] have some decided advantages, but a serious disadvantage is that they require a new set of names. In the Fedorov-Groth scheme of nomenclature one set of names is used for both general forms and classes; this is a decided boon to the student.

Names based upon merohedrism used by various crystallographers show a notable lack of uniformity. For the rhombohedral class $[AP_6 \cdot (C)]$ the following names based upon merohedrism have been used: rhombohedral hexagonal-tetartohedral, rhombohedral tetartohedral, hexagonal tetartohedral of the second sort, rhombohedral paramorphic, rhombohedral parahemihedral, and parallel-faced hemihedral. There has never been any generally accepted set of names for the merosymmetric classes of the various crystal systems that are based upon merohedrism.

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[19] *Mineralogy*, p. 280, London, 1902.

[20] *Mineralogy*, New York, 1912.

Names of classes based upon general forms, on the other hand, show little variation at the hands of their supporters. The differences are small, as, for example, hexakisoctahedral and hexoctahedral. It is important to note that practically all crystallographers who base class names upon general forms use Fedorov's plan of naming forms.

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VECTORIAL CHEMICAL ALTERATION OF CRYSTALS

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ABSTRACT

Instances of the vectorial chemical alteration of crystals occurring in nature are described for pyrite, stibnite, enargite, tourmaline and other species. With barite and celestite, a partial overgrowth of white opaque substance of later generation may simulate a vectorial alteration. Chemical changes in crystals may be influenced by twin structures, zoning in composition, and by the physical nature of the bounding surface. Nucleation on crystal edges or surface imperfections is described for the topochemical alteration of azurite to malachite.

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INTRODUCTION

The variation with crystallographic direction in the rate of chemical attack was noted, for calcite and other species, by Daniell (1816) and Brewster (1837).

The polyhedral solution, or reaction, bodies yielded by metathical chemical attack on spheres of calcite have been investigated by Goldschmidt and Wright (1), and similar studies have been made by others for a number of species. The bounding surfaces developed on such bodies, during the final stages of chemical attack, are perpendicular to the direction of greatest reaction velocity, and their orientation varies with the nature of the reagent, its concentration, and with the temperature.

Similarly, the simple decomposition of a crystalline compound may proceed with unequal velocities in different crystallographic directions, as in the thermal decomposition of certain copper compounds (2), potassium chlorate (3), and potassium hydrogen oxalate hemihydrate (4). With the latter substance, the velocity of reaction increases unequally for different directions with increase of temperature.

The dehydration figures—ellipsoids—formed on the surface of hydrous species, early studied by a number of investigators, particularly Pape (1864–68), Sohnke (1880–99) and Blasius (1885), and more recently by Gaudefroy (5) and others (2, 6), are also instances of vectorial decomposition. The vectorial "burn-figures" produced on the surface of calcined calcite crystals (7) and diamonds are related in origin. In such instances, the reaction proceeds only at the interface between the two phases; this relation also appears to be characteristic of polymorphic inversion (8). Ice (8*a*), thymol (8*b*), sulphur (8*c*) and other crystals vaporize vectorially.

A few instances of the natural vectorial alteration of minerals, mostly of the selective tarnishing of crystal faces, have been described by Leo (9) and Mügge (10). Leo's observations were made in connection with a study of the variation with crystallographic direction in intensity of etch stains on polished surfaces of ore minerals. Additional instances of the vectorial alteration of minerals, in all cases probably by metathical reaction, are described below.

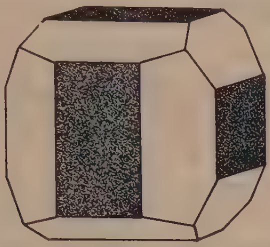

FIG. 1.

DESCRIPTION OF SPECIMENS

Pyrite

A vectorial alteration of pyrite to hematite is shown clearly by specimens from Rancagua, Chile, obtained recently (1932) by the American Museum of Natural History. The pyrite crystals average about 7 mm. in size and form closely packed drusy aggregates over slabs of wall rock. The habit is cubical, with large modifying faces of the pyritohedron (210). The cube faces are covered by a thick dark-brown to black film of iron oxide, while the faces of (210) are smooth and unaltered and possess the normal color and luster of the mineral (Fig. 1). When the film is flaked off, the pyrite surface is seen to be rather light in color and to be minutely pitted or frosted. The filming substance is hematite, but this mineral may have been derived from an original alteration layer of limonite.

The alteration was observed on several hundred crystals. Entirely unaltered crystals were present on the specimens, but there were no individuals on which both forms were altered. On one specimen, the crystals were unaltered, but were deeply etched on (100) and not on (210). On another specimen, smooth and brilliantly polished unmodified cubes were evenly tarnished in delicate shades of green and green-blue.

Watanabe (11) has observed that the intensity of the stain (hydrous ferric iron oxide) produced by an alkaline bromine solution on pyrite varies with the crystallographic direction. The stain is more intense on (100) than on (111). This observation had been made earlier by Leo (9), who also noted that the positive forms of pyrite were more readily attacked than the negative forms.

Enargite

Well formed crystals of enargite have been described by Weed (12) as occurring in vugs in veins at Butte, Montana, and " . . . it is notable that the terminal face has a clean, mirror-like surface and the prismatic faces a mossy coating of copper glance [chalcocite] . . . Specimens . . . show prisms of enargite surrounded by radial quartz, the basal pinacoids of the prisms being clean and mirror-like, and the remainder of the crystal coated with mossy glance."

The terminal forms of enargite (*luzonite*) crystals from Mancayan, Philippines, have been noted by Moses (13) to be decidedly lighter in color and less brilliant than the side planes. It is stated, however, that the cause of the effect is obscure, and that chemical alteration does not appear to have been operative.

Chalcopyrite, Galena

Jimbō (14) has noted the forms (111), $(1\bar{1}1)$ and (221) on twinned chalcopyrite crystals from the Abeshiro mine, Mutsu Province, Japan. The faces of $(1\bar{1}1)$ are black by oxidation, while the faces of (111) are brilliant and fresh. Ordinarily, the faces of (111) on chalcopyrite are oxidized (tarnished) and those of $(1\bar{1}1)$ unoxidized.

Greg and Lettsom (15) have remarked that the octahedral faces of galena are particularly liable to tarnish, and Leo (9) has cited several instances of such alteration.

A selective filming of galena cubo-octahedrons by chalcopyrite has been described (16), but this is owing to selective adsorption and super-crystallization and not to alteration. However, a described instance, of this origin, in which (100) of a galena cubooctahedron is selectively filmed by granular pyrite may be the result of alteration, particularly since the pyrite is not oriented to the galena.

Senaite

A peculiar instance, apparently of vectorial alteration, on crystals of senaite, $(Fe,Mn,Pb)O\cdot TiO_2$, from Diamantina, Minas Geraes, Brazil, in which the composition of the alteration product differs on different forms of the crystal, has been described by Hussak and Prior (17). These authors state that: "Some of the crystals are partially decomposed. In these cases the prism faces are covered with a brown coating of limonite, while the rhombohedral faces have a yellow earthy crust consisting of titanic acid, with only a trace of iron."

The crystals are tri-rhombohedral, like ilmenite. On unaltered crystals the rhombohedral planes are very bright, while the basal plane is uneven by twinning and, like the prism faces, is dull in luster.

Stibnite

A group of large stibnite crystals in the American Museum, from Baia Sprie (Felsöbanya), Roumania, was found to present a peculiar alteration in which the faces of the brachypinacoid (010), are coated by a yellow-brown mineral, probably wurtzite, to the exclusion of the other forms. The faces of (110) and of the terminating forms (113) and, occasionally (111) and (121), are not coated but are dull. The investing mineral not only incrusts the surface but extends into the substance of the crystal itself. As the alteration proceeds, all of the forms are coated.

The altered portion is identical in appearance and physical properties with the wurtzite crusts on stibnite crystals from this locality described by Prior (18) and Laspeyres (19), but no chemical tests were made to verify this identification. The greater attack on (010) was also noted by Laspeyres.

Prior observed that stibnite crystals from Siegen, Prussia, had their terminations wholly replaced by this substance. A similar instance, but in which the alteration product is probably cervantite, was found on crystals from Siena, Tuscany.

Tourmaline

Bischoff (20) has remarked that the alteration of tourmaline may commence on particular faces of the crystal; and that its alteration to mica sometimes takes place on one end of the prismatic crystals only, while the other end retains its original appearance. Blum (21) has described a similar instance in which one end of a tourmaline crystal is altered to talc, and Gümbel (22) and Mallet (22*a*) instances of polar alteration to white mica.

These descriptions do not state the end of the polar axis on which the alteration has taken place. However, it is probable that it is the antilogous pole, since the rate of attack by reagents is greatest at this pole (23)—i.e., along the *c*-axis towards the analogous pole. The correlation of rate of chemical attack with the rate of growth of particular forms, made by Leo (9) and others, would also be borne out in this case; since the polar secondary enlargements of tourmaline crystals described by Stow (24) and Alty (25) show that the rate of growth is greatest on the antilogous pole.

The influence on chemical attack of zones of varying composition in crystals is well illustrated by tourmaline. The interior zone of prismatic crystals may be altered to damourite, cookeite, etc., along the vertical axis (26), while the sides remain unaltered, and the disintegration may be carried to such an extent that the crystals are completely hollowed out. The interior of such tubular crystals may be lined with crystals of lepidolite, cookeite or other secondary minerals.A fibration parallel to the *c*-axis is sometimes developed in the initial stage of alteration.

Hitchen (27) has described tourmaline crystals from Fitchburg, Massachusetts, which are replaced by quartz along a central core, parallel to *c*. The well-known tourmaline shells—perimorphs—from Roe's Spar Bed, Crown Point, New York, enclosing a core of felspar, and from Newcomb, New York, enclosing a core of calcite, are probably skeletal growths and are not the result of interior replacement, or eutectic crystallization.

Wolframite

Frenzel (28) has briefly mentioned a wolframite crystal from Zinnwald, Bohemia, on which the prismatic faces are altered to scheelite, while the domical faces are unaltered.

The replacement of wolframite by scheelite along the (010) cleavages has been noted by Finlayson (29), and perpendicular to the (010) cleavages by Van Horn (30).

Barite

Barite crystals that apparently have undergone vectorial alteration have been described by Williams (31) and Chester (32) from

De Kalb, Jefferson Co., New York. The forms (001), (110), (104), (203), (102) and (011) were observed, of which the last three were superficially altered to a white chalky material. The crystals are peculiar in that they are outwardly hemimorphic, on the *b*-axis.

Seemingly altered barite crystals from this locality in the collection of the American Museum show the forms (011), (203), (104), (102) and (001). A white opaque chalky layer covers all but (001), and decreases in thickness on the forms in the order given. The surface of (001) is usually entirely free from the soft white material, but on several of the crystals the surface of this form, like that of (102), was covered by a thin milky-white translucent film. The layer on (011) may extend to a depth of 1 mm. or more. Although it is outwardly soft and chalky, it grades with depth into a relatively hard and compact mass. The interior of the crystals and, ordinarily, the faces of (001) are colorless and transparent.

Both Williams and Chester speak of the chalky surface layer as an alteration product, although Williams states that a qualitative chemical analysis showed it to be barium sulphate. Chemical examination of the Museum material, by R. B. Ellestad, University of Minnesota, also showed the chalky material to be barium sulphate of practically the same composition as the clear inner portion. No carbonate was found, and only traces of Sr and Ca; the water content was negligible.

Barite crystals are often found to have certain faces overgrown or zoned by a later generation of white, opaque barite; the initial crystal being partially enclosed as a phantom. The overgrowth in such instances is usually upon the prism (110), or a macro- or brachypinacoid or dome, with the base (001) remaining unchanged. The white borders on barite crystals of this nature from Morgan Co., Mississippi, were doubtfully ascribed by Broadhead (33) to chemical alteration; however, the appearance of the crystals is probably due to overgrowth, particularly since Broadhead described similar crystals, probably from the same locality, which are of this origin. Leudeking and Wheeler (34) found the color of the white bands in partially zoned barite crystals from Pettis Co., Missouri, to be caused by myriads of minute cavities.

The De Kalb barite crystals are probably also only instances of partial overgrowth, and not of alteration. The soft chalky nature of the surface may have been caused by the collapse, during superficial weathering, of highly porous material.

Pelikan (35) has described barite crystals particular forms of which have included a foreign pigmenting substance throughout their growth. Such occurrences are to be distinguished from partial overgrowths, already described, in which only particular forms of a pre-formed crystal have received deposition during a later period of growth.

Celestite

Celestite crystals from Put-in-Bay, Lake Erie, and Mokattam, Egypt, were said by Williams (31) to be altered similarly to the De Kalb barite crystals, but the occurrences are not well authenticated. The crystals from Mokattam sometimes have what appears to be a heavy brown alteration crust on certain forms. This effect is due either to the selective solution of these forms which allowed included foreign matter to project from their surfaces, or to a later partial overgrowth of brown, inclusion-rich, celestite on these forms (36). The latter feature is well shown by celestite crystals from Wadi-el-Tih, Egypt, in the Museum collection. The writer has seen celestite crystals from Put-in-Bay with white borders on certain faces, similar to specimens described by Troost (36*a*) but the formation of these crystals is clearly to be ascribed to partial overgrowth and not to alteration.

Aside from the vectorial aspect, chemical changes in crystals may be influenced by zoning in composition, by twinning structures, and, also, in the initial stages of attack, by the physical nature of the bounding surface.

NUCLEATION ON THE EDGES AND SURFACE IMPERFECTIONS OF CRYSTALS

Malachite Altering from Azurite

Nucleation in the decomposition of a solid salt generally starts on a crystal edge or preferably at a corner (4), nuclei in the center of a face being rare. The rate of reaction is constant for any given edge, but is different for different edges. Damaged regions—scratches, surface irregularities, etc.—behave like edges, as in the dehydration of copper sulphate pentahydrate and other hydrous species (2, 5, 6) and in the absorption of water by hydrocyanite (37). The boundaries of grains in crystalline aggregates are also loci of nucleation. The initiation of metathical reactions on the edges and corners of crystals, and the greater adsorptive power of these portions of the crystal surface, are well illustrated by mineral incrustations confined to the edges and corners of the incrusted crystal (38).

Frequently, the alteration of azurite to malachite seems to start at some point of imperfection on the surface of the crystal. This alteration involves the loss of carbon dioxide and the gain of water. Palache and Lewis (39) have described malachite pseudomorphs after azurite from Tsumeb, South Africa, and note that "The alteration has the appearance of starting at some center and progressively attacking fresh azurite, completely converting each crystal to malachite and spreading to the next at the point of contact." On one crystal "The malachite fibers radiate from one important center on the front pinacoid, and many interfering centers on the prism, giving a confused network of interwoven, splendant fibers. The front of the invading malachite is roughly concentric normal to the fibers." A number of excellent photographs of such altered crystals are given.

These writers have also described malachite pseudomorphs after azurite, from Bisbee, Arizona, and Tsumeb, which are overgrown by a later generation of azurite in parallel position to the original crystal. The malachite of the pseudomorphs apparently retains a structure adequate to control the orientation of the later azurite deposited on their surface (39). An identical occurrence, from Bisbee, has been described by Hills (40), who also noted the phenomenon of radial fibrous alteration, extending from the point of attachment.

Many malachite pseudomorphs after azurite from various localities present radial surface alteration. The alteration may start from one or more points on the surface of the crystal, but more frequently begins at the point of attachment to the matrix or along the plane of intersection with other crystals.

The free boundary of the altered area may be nearly circular, but is often ellipsoidal, and sometimes sharply so. The constituent fibers, which, on different specimens, range in size from indistinct silky threads to large needle-like prisms, generally terminate in a common boundary. However, individual fibers may sometimes project a considerable distance beyond the common front.

A feature of the alteration is an abrupt boundary between the unaltered azurite and the encroaching malachite. This was also noted by Palache and Lewis. The alteration seems to progress more rapidly over the surface of the azurite, and a thin fibrous layer may cover an otherwise unaltered crystal. In the final stages of alteration, the crystal may be entirely replaced by a few radiating bundles of fibers.

Analogous alterations have been observed with other, artificial, copper compounds, and all may be classed in Kohlschütter's category of "topochemical" reactions.

Chemical Alteration of Twinned Crystals

From the work of Judd (41) and others, the composition planes of secondary twinning lamellae are well known to be directions of relatively rapid chemical attack and solution.

The lines of intersection of two twin planes in repeatedly twinned calcite crystals may be marked by tubular solution cavities—the "höhle Canalen" of Rose and von Koksharov. In one instance (42), the loci of such planes were found to be replaced by a lattice-like arrangement of rods of spadaite.

Canfield (43) ascribed the interior "walls" in hollow pseudomorphs of quartz after anhydrite from New Jersey to replacement along twin planes, as a consequence of the greater rate of solution of such planes, but this view is not verified by recent work. No mention of twinning is made in Schaller's study (44) of the quartz—anhydrite pseudomorphs of this region, and the quartz walls are ascribed to parallel growth and to penetration along cleavages.

Ichikawa (45) observed that the alteration to mica of pseudohexagonal trillings of cordierite from Japan was most extensive along the composition planes of the crystal. Funnel-shaped altered regions also extended in from the (001) faces of the crystal along the vertical axis—the locus of intersection of the composition planes.

Chemical Alteration of Zoned Crystals

The velocity of reaction in the decomposition of crystalline solids is, in general, decreased by the presence of foreign substances in solid solution. Differential effects may be expected as a consequence of composition zoning, or of the zonal adsorption of impurities, during crystal growth. Inequalities in the rate of reaction caused by adsorbed impurities have been noted for KH oxalate hemihydrate (4).

A selective alteration along zones of more favorable composition has been described for tourmaline on a preceding page. Schouten (46) has described a synthetic zonal replacement of pyromorphite by galena by reaction with an alkaline polysulphide solution, and also several naturally occurring instances of this nature among other minerals. The replacement of pyromorphite by galena in nature has been said (10) to progress more rapidly in the (0001) direction.

Zonal alteration is of frequent occurrence in plagioclase, in which case the inner calcic zones may be preferentially altered to secondary calcic minerals. Similarly, the albite lamellae in perthites may be preferentially altered or replaced, as by tourmaline (47) and bornite (48). Sometimes the albite lamellae may apparently be left as replacement residuals, as in an instance of replacement by fluorite (49).

The writer is indebted to Mr. Herbert P. Whitlock for opportunity to study the specimens described from the collection of the American Museum of Natural History.

References

1. Goldschmidt, V., and Wright, F. E., *Neues Jahrb., Beil.-Bd.* vol. **17,** 1903, pp. 355–390; *Beil.-Bd.* vol. **18,** 1904, pp. 335–376.
2. Kohlschütter, V., and Luthi, M., *Helvetica Chim. Acta,* vol. **13,** 1930, pp. 978–1006.
3. Coppock, J. B. M., Colvin, J., and Hume, J., *Trans. Faraday Soc.,* vol. **27,** 1931, p. 283, 4 figs.
4. Hume, J., and Colvin, J., *Proc. Royal Soc. London,* vol. **125A,** 1929, pp. 635–646.
5. Gaudefroy, C., *Bull. soc. min. franc.,* vol. **42,** 1919, pp. 284–380.
6. Bright, N. F. H., and Garner, W. E., *Nature,* vol. **133,** 1934, p. 570; *Jour. Chem. Soc. London,* **1934,** pp. 1872–1877.
7. Rinne, F., *Festschrift V. Goldschmidt,* Heidelberg, **1928,** pp. 213–220, 9 figs.
8. Coppock, J. B. M., *Nature,* vol. **133,** 1934, p. 570.

8*a*. Meigs, J. A., *Jour. Acad. Nat. Sci. Phil.,* ser 2, vol. **3,** 1855, p. 126; Adams, J. M., *Proc. Royal Soc. London,* vol. **128A,** 1930, p. 588.

8*b*. Aminoff, G., *Zeit. Kryst.,* vol. **61,** 1925, pp. 373–379.

8*c*. Aminoff, G., *Zeit. Kryst.,* vol. **65,** 1927, pp. 632–635.

9. Leo, Max: *Ueber Anlauffarben, ihre künstliche Herstellung und Verwertung zur Unterscheidung und orientierung opaker Körper, speziell der gelben Kiese.* Dresden, **1910,** pp. 72, (Inaug.-dissert., München).
10. Mügge, O., *Neues Jahrb., Beil.-Bd.,* vol. **16,** 1903, pp. 350, 446–447.
11. Watanabe, M., *Sci. Papers Tohoku Imp. Univ.,* ser. 3, vol. **2,** 1924–5, pp. 31–37.
12. Weed, W. H., *U. S. Geol. Survey, Prof. Paper* **74,** 1912, pp. 77–78.
13. Moses, A. F., *Am. Jour. Sci.,* ser. 4, vol. **20,** 1905, p. 277.
14. Jimbō, K., *Beiträge zur Mineral. Japan,* no. **5,** 1915, pp. 264–265.
15. Greg, R. P., and Lettsom, W. G., *Manual of Mineralogy,* London, **1847,** pp. 412, 413.

16. Frondel, C., *Am. Mineral.*, vol. **19,** 1934, pp. 322–323; *Amer. Mus. Nat. Hist. Novitates*, no. **695,** 1934, p. 1.
17. Hussak, E., and Prior, G. T., *Mineralog. Mag.*, vol. **12,** 1898, pp. 31–32.
18. Prior, G. T., *Mineralog. Mag.*, vol. **9,** 1892, p. 9.
19. Laspeyres, H., *Zeit. Krist.*, vol. **9,** 1884, pp. 186–192.
20. Bischoff, G., *Chemical Geology*, London, vol. **2,** 1855, pp. 261–262.
21. Blum, J. R., *Die Pseudomorphosen des Mineralreichs*, Stuttgart, **1843,** p. 134.
22. Roth, J., *Allgem. und Chem. Geol.*, Berlin, vol. **1,** 1879, p. 372.

22*a*. Mallet, F. R., *Geol. Surv. India, Mem.*, vol. **5,** 1866, p. 172.

23. Kulaszewski, C., *Ber. sächs. Akad. Wiss. Leipzig, Math.-phys. Kl.*, vol. **72,** 1920, pp. 48–55.
24. Stow, M., *Am. Mineral.*, vol. **17,** 1932, p. 150.
25. Alty, S. W., *Am. Mineral.*, vol. **18,** 1933, pp. 351–355.
26. Bischoff, G., *op. cit.*, pp. 253–266; Roth, J., *op. rit.*, pp. 369–372; Leidy, J., *Proc. Acad. Nat. Sci. Phil.*, **1871,** p. 245; Teschemacher, J. E., *Boston Jour. Nat. Hist.*, vol. **4,** 1844, p. 36; Penfield, S. L., *Am. Jour. Sci.*, ser. 3, vol. **45,** 1893, p. 395; Bastin, E. S., *U. S. Geol. Surv., Bull.* **445,** 1911, pp. 60, 89; Hamlin, A. C., *The Tourmaline*, Boston, 1873, pp. 65, 67.
27. Hitchen, C. S., *Am. Mineral.*, vol. **20,** 1935, pp. 5, 12; Pl. A, figs. 3, 4.
28. Frenzel, A., *Mineralog. Lexicon für Sachsen*, Leipzig, **1874,** p. 372.
29. Finlayson, A. M., *Econ. Geol.*, vol. **5,** 1910, p. 721.
30. Van Horn, F. R., *Am. Mineral.*, vol. **15,** 1930, p. 461.
31. Williams, G. H., *Johns Hopkins Univ. Circulars*, no. **29,** 1884, p. 61.
32. Chester, A. H., *Am. Jour. Sci.*, ser. 3, vol. **33,** 1887, pp. 288–289.
33. Broadhead, G. C., *Am. Jour. Sci.*, ser. 3, vol. **13,** 1877, p. 419.
34. Luedeking, C., and Wheeler, H. A., *Am. Jour. Sci.*, ser. 3, vol. **42,** 1891, p. 495.
35. Pelikan, A., *Tschm. Min. Mitth.*, vol. **16,** 1896, p. 24.
36. Bauermann, H., and Foster, C. Le Neve, *Phil. Mag.*, vol. **38,** 1869, p. 162.

36*a*. Troost, G., *Jour. Acad. Nat. Sci. Phil.*, vol. **2,** 1822, p. 302.

37. Dana, E. S., *System of Mineralogy*, N. Y., 6th ed., **1900,** p. 912.
38. Frondel, C., *Amer. Mus. Nat. Hist. Novitates*, no. **759,** 1934, pp. 1–11.
39. Palache, C., and Lewis, L. W., *Am. Mineral.*, vol. **12,** 1927, pp. 133–134; figs. 31, 34–37; frontis., figs. A, B.
40. Hills, R. C., *Proc. Colo. Sci. Soc.*, vol. **3,** 1891, p. 258.
41. Judd, J. W., *Mineralog. Mag.*, vol. **7,** 1886, p. 81; vol. **8,** 1889, p. 186; vol. **11,** 1895, p. 49.
42. Graham, R. P. D., *Mineralog. Mag.*, vol. **18,** 1918, pp. 252–258, Pls. 8, 9, 10.
43. Canfield, F. A., *Am. Mineral.*, vol. **2,** 1917, p. 48.
44. Schaller, W., *U. S. Geol. Survey, Bull.* **832,** p. 24.
45. Ichikawa, S., *Am. Jour. Sci.*, ser. 4, vol. **42,** 1916, pp. 116–117, Pl. 3.
46. Schouten, C., *Econ. Geol.*, vol. **29,** 1934, pp. 619, 622, figs. 1, 5, 6, 11.
47. Brammall, A., and Harwood, H. F., *Mineralog. Mag.*, vol. **20,** 1925, p. 321, fig. 2.
48. Tolman, C. F., and Rogers, A. F., A Study of the Magmatic Sulphide Ores: *Stanford Univ. Publ.*, **1916,** p. 58, fig. 59.
49. Tolman, C., and Goldich, S. S., *Am. Mineral.*, vol. **20,** 1935, p. 237, fig. 6.

THE MORPHOLOGY OF PHENACITE FROM TWO NEW OCCURRENCES

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In the course of an extended morphological study of phenacite, it was found that two new and as yet incompletely described localities had been discovered in the past few years. This paper is a

Table I

Revised Angle-Table for Phenacite

No.	Letter	G_2 Symbol	Bravais	ϕ	ρ
1.	**c*	0	0001	00°00′	00°00′
2.	*a*	$\infty 0$	$11\bar{2}0$	00 00	90 00
3.	*k*	2∞	$5\bar{1}\bar{4}0$	40 54	90 00
4.	*m*	∞	$10\bar{1}0$	30 00	90 00
5.	*K*	$\frac{1}{2}\infty$	$41\bar{5}0$	19 06	90 00
6.	*P*	10	$2\bar{1}\bar{1}3$	60 00	23 47
7.	*p*	01	$11\bar{2}3$	00 00	23 47
8.	**H*	$\frac{3}{2}0$	$2\bar{1}\bar{1}2$	60 00	33 28
9.	O	20	$4\bar{2}\bar{2}3$	60 00	41 23
10.	*o*	02	$22\bar{4}3$	00 00	41 23
11.	*d*	$\frac{1}{2}$	$10\bar{1}2$	30 00	20 53
12.	*d*·	$-\frac{1}{2}$	$01\bar{1}2$	−30 00	20 53
13.	*r*	1	$10\bar{1}1$	30 00	37 21
14.	*r*·	-1	$01\bar{1}1$	−30 00	37 21
15.	*μ*·	-2	$02\bar{2}1$	−30 00	56 46
16.	*N*	$\frac{1}{4}1$	$21\bar{3}4$	10 53	26 47
17.	*ν*	$1\frac{1}{4}$	$3\bar{1}\bar{2}4$	49 07	26 47
18.	**I*	$\frac{1}{2}1$	$41\bar{5}6$	19 06	30 14
19.	**i*	$1\frac{1}{2}$	$5\bar{1}\bar{4}6$	40 54	30 14
20.	**L*	$1\frac{3}{2}$	$71\bar{8}6$	23 25	43 51
21.	**l*	$\frac{3}{2}1$	$8\bar{1}\bar{7}6$	36 35	43 51
22.	Λ	$1\frac{5}{2}$	$31\bar{4}2$	16 06	54 00
23.	*S*	14	$21\bar{3}1$	10 53	63 39
24.	*s*	41	$3\bar{1}\bar{2}1$	49 07	63 39
25.	Σ	17	$32\bar{5}1$	6 35	73 16
26.	*B*	$\frac{1}{4}\frac{7}{4}$	$32\bar{5}4$	6 35	39 45
27.	*b*	$\frac{7}{4}\frac{1}{4}$	$5\bar{2}\bar{3}4$	53 25	39 45
28.	*z*·	$-\frac{5}{4}\frac{1}{2}$	$13\bar{4}4$	−16 06	34 32
29.	*X*·	$-\frac{1}{2}2$	$\bar{1}3\bar{2}2$	−49 07	45 17
30.	*x*·	$-2\frac{1}{2}$	$12\bar{3}2$	−10 53	45 17
31.	*γ*·	$-\frac{7}{2}\frac{1}{2}$	$23\bar{5}2$	− 6 35	58 59
32.	**V*·	$-\frac{2}{5}\frac{3}{5}$	$\bar{1}8\bar{7}5$	−36 35	21 01
33.	**v*·	$-\frac{3}{5}\frac{2}{5}$	$17\bar{8}5$	−23 25	21 01
34.	Ξ·	-25	$\bar{1}4\bar{3}1$	−43 54	70 02
35.	*ξ*·	-52	$13\bar{4}1$	−16 06	70 02

portion of the longer work; its purpose is to put the characteristic habits of the crystals from these localities on record.

The two new localities are Klein-Spitzkopje, Southwest Africa, and the Morefield mine, near Winterham, Amelia County, Virginia. Through the kindness of Alexander Hahn, of Idar-on-the-Nahe, Germany, a complete suite of specimens and loose crystals was available for the study of the first locality. From the latter locality, several specimens were available, three of which were loaned by Dr. W. F. Foshag of the U. S. National Museum, and five by Miss Jewel J. Glass of the U. S. Geological Survey. The greater part of the work was done in the Victor Goldschmidt Institut für Kristallforschung, Heidelberg, Germany.

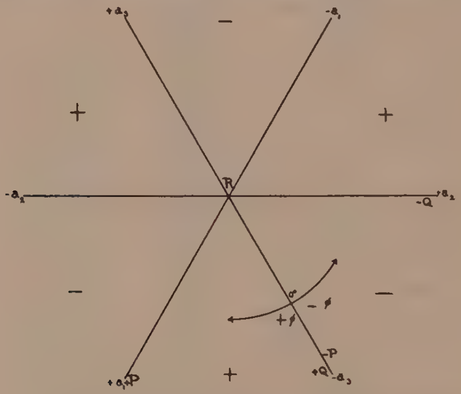

FIG. 1. Diagram showing the manner of listing of the ϕ angles in the new angle-table.

The angle-table gives the new forms found in the complete study and includes those which are new on the crystals from the two localities. The forms whose letter is preceded by an asterisk are new. The symbols and co-ordinate angles are calculated on the generally accepted elements.

$$c = 0.6611 \text{ (Koksharov)}$$
$$p_0 = 0.4407$$

As shown in Fig. 1, the azimuth angles ϕ refer to the negative end of the a_3- axis as prime meridian, reading from 0° to +60° and 0° to −60° in the adjacent positive and negative sextants, respectively. Positive forms thus receive positive azimuth angles and negative forms negative azimuths. This convention has been adopted to obtain exact correspondence between the position angles and the Bravais symbols.

With the polar axes P, Q designated as in Fig. 1, the Goldschmidt symbol p, q defines the position of a pole in the right or left part of the sextant enclosed by the polar axes. A negative sign prefixed to the symbol p, q places the pole in the negative sextant. The Goldschmidt symbol p, q is related to the Bravais symbol $(hk\bar{i}l)$ by the following equation:

$$p=(h-k)/l \qquad h/l=(2p+q)/3$$
$$q=(h+2k)/l \qquad k/l=(q-p)/3$$

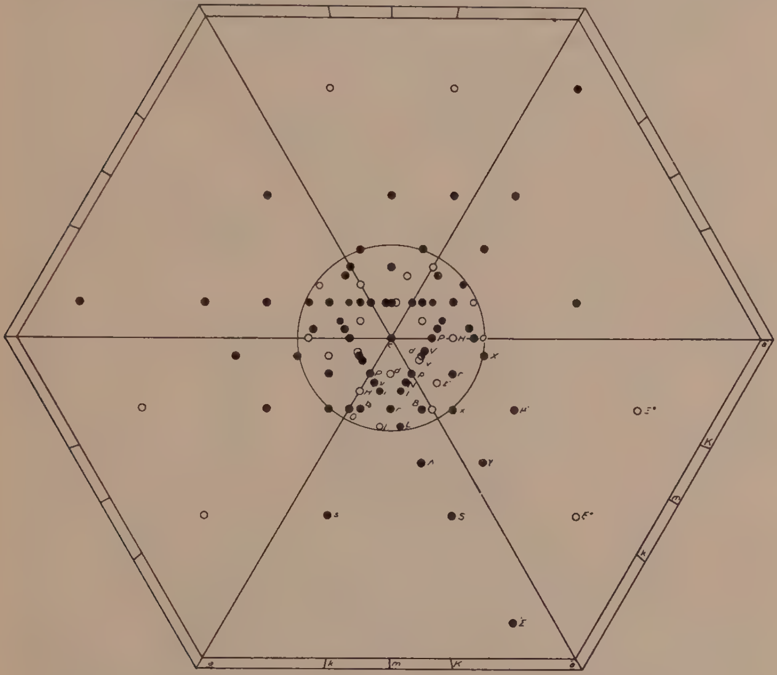

FIG. 2. Gnomonic projection of all the certain forms of phenacite.

The equations are strictly true in the positive sextant. In the negative sextant the indices and sign of the Bravais symbol must be appropriately interchanged.

A convention has been adopted in the lettering of the forms for the new angle-table. All right forms are distinguished by capital letters and left forms by small letters. Forms lying in the negative sextant are distinguished from those in the positive sextant by dots which follow the letters of the negative forms. Fig. 2 is a gnomonic projection showing all of the established forms of phenacite, derived from the study of all of the occurrences.

KLEIN-SPITZKOPJE, SOUTHWEST AFRICA

Klein-Spitzkopje, formerly called Kainsberg or Keinsberg, is situated 100 km. northwest of Swakopmund, Southwest Africa. For several years it has been the source of beautiful, well-terminated aquamarine crystals. The occurrence has been briefly described by Reuning.[1] Topaz from the same occurrence has been described by Hintze[2] and Himmelbauer.[3] Recently, Spencer[4] has described two crystals from the locality, indicating two habits. The phenacite probably occurs in the same dikes as the beryl, but in only one specimen had the crystals actually grown upon a beryl crystal. The study showed that the phenacite crystals from this locality are of two distinct types, apparently originating in two different, although closely associated pegmatite dikes.

The specimens of type 1 consisted of ninety-eight small, loose crystals and two matrix specimens. The loose crystals are prismatic in habit and many are doubly terminated. Commonly these show no signs of attachment and appear to have been found loose in pockets of clayey mud, remnants of which is to be seen on the crystals. Some have grown together into small groups with random orientations. The matrix specimens show a gangue of quartz with a few attached crystals of phenacite and several small brownish feldspar crystals. These specimens have a slightly weathered apappearance, in contrast to the freshness of the specimens of type 2.

Of the second type of material, forty-three specimens were studied. These are strikingly different in habit, being lenticular and almost without prism faces. All of these crystals are small and attached to matrices of microcline or smoky quartz, with associated muscovite, topaz, tourmaline, and siderite. The quartz and feldspar are often coated on one or more sides with black tourmaline needles, but in no case do these needles cover the phenacite crystals. In one or two cases, however, it was noted that the ends of the tourmaline needles are included by the outer portions of the phenacite crystals. Another specimen shows a small phenacite crystal entirely included within a large topaz crystal. The same specimen shows mutual interference between the topaz and quartz.

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[1] Reuning, E., Pegmatit und Pegmatitmineralien in Südwest Afrika: *Zeit. Krist.*, vol. **58**, pp. 448–459, 1923.

[2] Hintze, C., Ueber Topas aus Südwest Afrika: *Zeit. Krist.*, vol. **15**, pp. 505–509, 1889.

[3] Himmelbauer, A., Kristallographische Untersuchungen an einigen Afrikanischen Topasvorkommen: *Festschrift V. Goldschmidt*, Heidelberg, pp. 147–153, **1928.**

[4] Spencer, L. J., Some Beryllium Minerals from Southwest Africa: *Mineralog. Mag.*, vol. **23**, pp. 616–623, 1934.

The suite is sufficiently diverse to allow one to draw some conclusions concerning the order of crystallization. From the specimens described, it is clear that quartz was the earliest mineral to form, followed closely by muscovite, microcline, topaz and then phenacite. The tourmaline may have preceded the phenacite, but it is also possible that it developed later, replacing small portions of the earlier crystals of quartz and feldspar in growing upon their surfaces. All of the minerals show widely overlapping relationships.

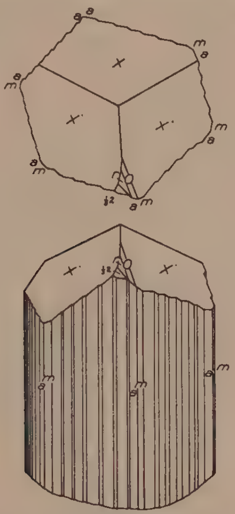

FIG. 3. Lower end of a Klein-Spitzkopje crystal of type 1, showing the form $\frac{1}{3}2$ and the striated appearance.

The prismatic crystals of type 1 are of variable apearance, ranging from transparent and colorless to an opaque gray which is probably caused by the inclusion of impurities. None attains great size, the largest group being but 20 mm. long. One of the largest single crystals measures 15 by 7.5 mm.; the average size is approximately 10 by 4 mm. The crystals are fresh in appearance and but slightly etched, giving bright though diffuse signals on the goniometer. They are remarkably uniform in habit and poor in forms. The resemblance of these crystals to some of the Mt. Antero, Colorado, crystals is striking.

As in the Mt. Antero crystals, the prism zone, with strong vertical striations is dominant (Fig. 3). These striations result in a rounding of this zone and a lack of well-defined, sharp-edged prism faces. Therefore, the signal on the goniometer is a continuous train-of-reflections[5] extending from *a* $(11\bar{2}0)$ to *m* $(10\bar{1}0)$. It contains no particularly strong point which would correspond to another prism form.

The termination is always dominated by $X^{\cdot}$ $(\bar{1}3\bar{2}2)$, again just as in the case of the Mt. Antero crystals. Of the secondary forms the most common is *r* $(10\bar{1}1)$, and in diminishing frequency *S* $(21\bar{3}1)$, *s* $(3\bar{1}\bar{2}1)$, $d^{\cdot}$ $(01\bar{1}2)$, and lastly *p* $(11\bar{2}3)$ and *P* $(2\bar{1}\bar{1}3)$, always as small narrow faces. The form $r^{\cdot}$ $(01\bar{1}1)$, though a common form elsewhere, was not observed.

It was noted that the rarer forms on the cloudy and gray crystals lie between $X^{\cdot}$ and the prisms, while on the clear crystals they lie near the apex, as faces of $d^{\cdot}$, *p*, and *P*. This suggests the possibility that the inclusions have influenced the development of the crystals.

The form $X^{\cdot}$ exhibits clear-cut accessories, in most cases covering the entire face. Similar accessories were noted in other occurrences on the same form. They consist of small rounded hillocks, which sometimes give reflections from the bounding planes corresponding to $d^{\cdot}$, *p*, *P* and the prism faces. The edge between two $X^{\cdot}$-faces often shows small planes parallel to *r*, resulting from the intersection of the accessories on $X^{\cdot}$.

The faces of the other rhombohedrons are usually small and even giving good signals. The prisms are narrow and have no outstanding accessories, their striations have little similarity to the Framont-Mt. Antero type, except that they both give continuous trains through one side of a sextant, This train usually extends from *a* to *m*, with the adjoining half sextant dark, with the train recommencing at *a*.

Reflections in the position of the base, *c* (0001), a new form for phenacite, were found three times upon etched crystals. They result from corrosion figures on $X^{\cdot}$. On the goniometer it was further observed that three trains extend from the base to the position of $d^{\cdot}$. The surfaces giving these reflections have also originated through etching.

One probable new form, $\frac{1}{3}2$ $(8{\cdot}5{\cdot}\overline{13}{\cdot}9)$ was observed as a small face to the right of *r* on three of the crystals. It was dull and gave unsatisfactory readings. The form is shown on the lower end of a crystal in Fig. 3, but it requires confirmation.

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[5] German: *Lichtzug, Reflexzug.*

Measured: $\phi = 7°26'$ Calculated: $\phi = 7°35'$
$\rho = 43°40'$ $\rho = 43°56'$

The new form $V\cdot$, $-\frac{23}{55}$ $(\bar{1}\cdot 8\cdot \bar{7}\cdot 15)$ was observed once as a small face intergrown with $d\cdot$. Since it has commonly been found on crystals from other localities, it may be considered certain.

Measured: $\phi = 35°42'$ Calculated: $\phi = 36°35'$
$\rho = 21°35'$ $\rho = 21°01'$

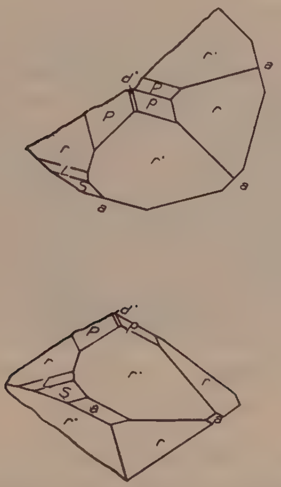

FIG. 4. Klein-Spitzkopje crystal of type 2, showing the new form *L*.

In summary, a statistical survey of the forms present on the crystals of type 1 show: *a*, *m*, and *X*· to be dominant, *r*, *S*, *s*, *d*·, *p*, and *P* moderately frequent in their occurrence and all others to be very rare.

The crystals of type 2 range in size from very minute up to a maximum diameter of 13 mm., with a thickness of 6 mm. The average diameter is about 5 mm. They vary from quite colorless and transparent to milky and translucent, and they are free from chloritic and hematitic inclusions. Although the crystals are bright and fresh, many of them show the effects of etching, the edges being frequently rounded, particularly near the equatorial zone. All the crystals of this type have similar habits, and resemble rhombohedral crystals from Ilmengebirge, Florissant, and New Hampshire.

On these crystals the forms of the prism zone are often absent, and when present they play but a minor role. The forms *a* and *m* were both observed, but no other prism forms were found. The faces are smooth and free from accessories.

Of the terminal forms, *r* and *r*· are dominant; *P* and *p* are also common, occasionally equalling *r* and *r*· in size and even, in one or two cases, becoming dominant. Other forms, most frequently *S* and *s*, then *d*·, and least often *X*· and *x*·, were also observed, but always as small facets.

Several new forms were found, but none, with the exception of $H(2\bar{1}\bar{1}2)$, $L(71\bar{8}6)$ and $l(8\bar{1}\bar{7}6)$, found elsewhere as well, can be called certain. The forms *L* and *l* lie above *S* and *s* in the zones [*aSr*] and [*asr*], as narrow faces giving good signals; they were each seen twice (Fig. 4). The angles for the form are:

	Measured:		Calculated:	
$L(71\bar{8}6)$	$\phi=23°00'$		$\phi=23°25'$	
		$\rho=44°46'$		$\rho=43°51'$
$l(8\bar{1}\bar{7}6)$	$\phi 37°00'$		$\phi=36°35'$	

The new form *H*, $0\frac{3}{2}(2\bar{1}\bar{1}2)$ was observed three times on one crystal. It lay exactly in the [*Pa*] zone and gave poor measurements.

Measured: $\phi=60°00'$ Calculated: $\phi=60\ 00'$
$\rho=32°46'$ $\rho=33°28'$

The surface of the *r*·-faces is distinctive in its appearance and a glance at the accessories usually suffices to distinguish the form from *r*. The accessories on *r*· are well-developed, the face being commonly covered with many small oval hillocks, whose long axes lie in the zone [*rm*] (Fig. 5). Because of the character of this surface, the face usually appears dull and gives blurred signals. The faces of *r*, on the other hand, are usually brilliant and distinctive accessories are rare. When present, they usually take the form of a single central mound, larger than those of *r*· but similar in form. The faces of *P* and *p* were, in several instances, observed to have small rounded mound-like accessories (Fig. 6) but they are much rarer than those on *r*· and therefore the danger of confusing the forms is not great. The faces of the other forms are all small and brilliant, without distinctive accessories.

Many of the crystals appear to have been somewhat etched, about half of them showing this phenomenon. The results of this attack are quite distinctive and different from that seen on crystals from other localities. The etching is to be observed only upon the faces lying near the prism zone; it has resulted in a rounding off of the edges in most cases without regard to the positive or negative character of the rhombohedron so attacked. Although the surfaces developed in this manner are smooth, no satisfactory measurements or symbols were obtained. In several cases the etching has taken the form of a shallow trenching along the equatorial edges. However, the faces themselves have not been appreciably etched and the *rr* edges are always sharp.

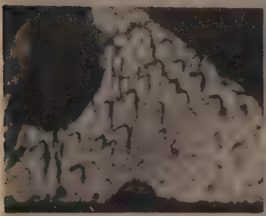

Fig. 5. Klein-Spitzkopje crystal of type 2, showing mound-like accessories on *r*·.

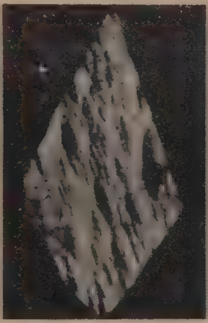

Fig. 6. Klein-Spitzkopje crystal of type 2, showing ridges on *P*.

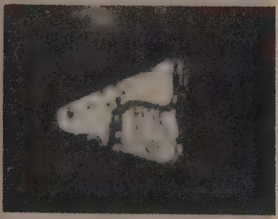

Fig. 8. Amelia Courthouse crystal, showing etch pits on *a*.

The crystals show another peculiarity in their tendency to be distorted near the contacts with the matrix. Faces of the same form near the contact have variable ρ angles, with the portion in contact often showing more deviation from the normal position than the more distant part.

A statistical summary of the 44 crystals studied shows *r* and *r*· to be invariably present. On 26, *r* is dominant and determines the habit; *r*· is dominant on but 4 crystals, and *p* and *P* likewise on 4 crystals. On 9 crystals *r* and *r*· were so equally developed that it was not possible to say which was the more important, and in one case, *p* and *P* are equal to the former pair in their importance.

Crystallographically, the two types of phenacite from Klein-Spitzkopje are distinct and definitely non-gradational. Because of their close geographic occurrence they must have a genetical relationship, and a study of the actual field relationships of the pegmatites in which they occur should give some interesting information upon the relation of crystal habit to the conditions of crystallization.

MOREFIELD MINE, AMELIA COUNTY, VIRGINIA

The second new phenacite find of the past few years is not far distant from the occurrence partially described long ago by Yeates.[6] The specimens mentioned by Yeates were found at the Rutherford Mine, near Amelia Courthouse, but not far from Winterham, the nearest town to the Morfield deposit.

Some descriptions of the newly opened deposit have appeared. The first reference to it was in a brief note by the owner[7] and since then Glass[8] has published a description of the rare earth minerals of the dike and has a longer paper in preparation upon the same aspects.[9] The pegmatite is apparently the same sort of dike as those of the Ilmengebirge, Florissant, and Klein-Spitzkopje. The principal associates of the phenacite are microcline, beryl, quartz, topaz and a mica said to have the composition of zinnwaldite. Many other minerals are found in small quantities in the dike.

About fifteen specimens of phenacite from the locality were available for the study. The largest consists mainly of beryl, with some quartz, microcline, and muscovite, and several embedded white translucent anhedrons of phenacite about 2 cm. in length. A similar specimen has several embedded crystals of phenacite, one of which shows some free faces. The crystal is rough and dull and permits only approximate contact goniometer measurements. The forms present are: *a* (large), *m* (medium), *r* (medium), *P* and *p* (the dominating forms), and *d*· (small). The faces are dulled by etching, but are without distinctive etch figures. Several other crystals of this type were seen and all present the same aspect and forms.

Although the small crystals show the same forms in the same relative development, they are very different in their appearance. The crystals of this group are small, the largest not exceeding 4 or

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[6] Yeates, W. S., New Localities for Phenacite: *Am. Jour. Sci.*, Ser. III, vol. **40**, p. 259, 1890.

[7] Morefield, S. V., Letter in *Rocks and Minerals*, vol. **8**, pp. 143–144, 1933.

[8] Glass, J. J., Rare Chemical Constituents of the Amelia Pegmatite Dikes and their Mineral Sources: *Trans. Am. Geophys. Un.*, 15 Meet., **1934**.

[9] Glass, J. J., The Pegmatite Minerals from near Amelia, Va.: *Am. Mineral.*, vol. **20**, pp. 741–768, 1935.

5 mm. in diameter, and are colorless and transparent. They are found completely embedded in microcline, and the crystal form is very well developed on most. Ten of these crystals were measured on the goniometer. All are short prismatic and show both *a* and *m* in the prism zone. The forms *r*, *P* and *p* are invariably present, usually with *r* dominant and *P* and *p* smaller but nearly equal in size (Fig. 7). Etching has rounded some of the edges, but in two cases *d*· is unmistakably present. The *r*-faces are small, occurring three times on the ten crystals. *S*, *X*· and *z*· were each seen once. One possible new form, lying in the [*z*·*a*] zone was observed as a single small face on one crystal, (U. S. N. M. #96749). Its symbol would correspond most nearly to $(3\cdot 11\cdot \overline{14}\cdot 12)$. The angles are:

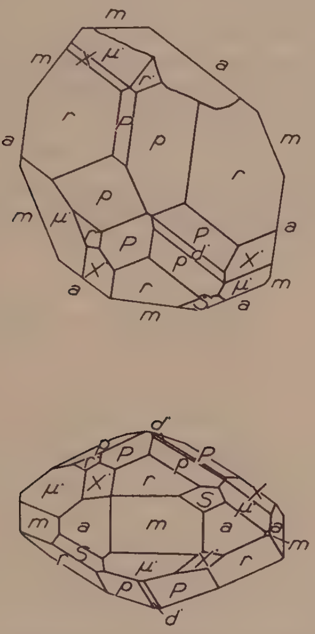

Fig. 7. Typical Amelia Courthouse, Virginia, crystal.

Measured: $\phi=-12°27'$ Calculated: $\phi=-12°10'$
$\rho=\ 43°10'$ $\rho=\ 42°03'$

All of the crystals show considerable etching, sometimes over the entire crystal and sometimes over only the upper or lower portion. The etched faces give somewhat diffuse signals, many parts of their surfaces giving reflections corresponding to other forms. Reflections of this sort from P and p correspond to $d^{\cdot}$, r, and $r^{\cdot}$; those from $r^{\cdot}$ correspond to $d^{\cdot}$ and $\mu^{\cdot}$; and those from r to S and s. Distinctive etch pits of the type seen upon the Brazilian crystals upon a were observed (Fig. 8), although they were not common.

Summary

In the study of these two new localities we find crystals representing all three of the habits found to be common to phenacite: prismatic, short prismatic, and rhombohedral. The customary relations exist, that is, the rhombohedral and prismatic crystals are not found in close association. The matrix of the rhombohedral crystals seems typically to contain no beryl, a phenomenon noted at other occurrences as well. The rarity of the form $d^{\cdot}$ on crystals from the Morefield mine is noteworthy, for it is usually a dominant form. The tetartohedry is pronounced on all the crystals and several new forms, $V^{\cdot}$, H, L and l, were observed.

NOTES AND NEWS

REPLACEMENT IN FILLED FISSURE VEINS

B. M. SHAUB, *Cornell University, Ithaca, New York.*

Metasomatic processes have been described at length in numerous papers[1] on the subject, but these deal with the replacement processes in practically solid rock, or along shear planes.

When fractures or other cavities containing mineral matter showing a crustified structure are referred to or described, it is usually either intimated or stated that the several crusts or bands have been deposited one on the other, no suggestion being made that the minerals of a later crust may to any extent replace those of an earlier one.

If a fracture after being filled with vein matter has been reopened the material deposited later is likewise commonly spoken of as *filling* the fracture.

In either case there seems no valid reason why some of the minerals of one crust should not in part replace those of an earlier crust since in many cases metasomatic relationships are found to exist between similar minerals under other conditions.

It is possible that the idea of replacement under the conditions mentioned does not suggest itself because the contact between adjoining bands often appears quite sharp when examined megascopically.

The writer has had occasion to examine a number of banded, brecciated and massive vein specimens from America and foreign localities, all of them being in the Cornell University collection. In the study of thin and polished sections it was interesting to find in how many cases there was undoubted evidence of replacement along the boundary line between two bands or between minerals succeeding each other in time of crystallization.

Fig. 1 represents a vein in the black dolomitic limestone from Austinville, Va. Megascopically the walls of the fracture appear quite sharp. Next to the walls there are white bands of dolomite, these are followed by darker irregular bands of sphalerite and pyrite deposited in the order named, while in the center there is sometimes another band of dolomite. A thin section of one of these veins (Fig. 2A) shows the dolomite on the borders with the sphalerite

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[1] Lindgren, Waldemar, Metasomatic Processes in Fissure-veins: *A.I.M.E., Trans.*, vol. **30**, pp. 578–692, 1900.

Irving, J. D., Replacement Ore-bodies and the Criteria for their Recognition: *Econ. Geol.*, vol. **6**, pp. 527–561, 1911.

Lindgren, Waldemar, Mineral Deposits, 3rd Edition, p. 196, **1928**, McGraw-Hill Book Co., New York.

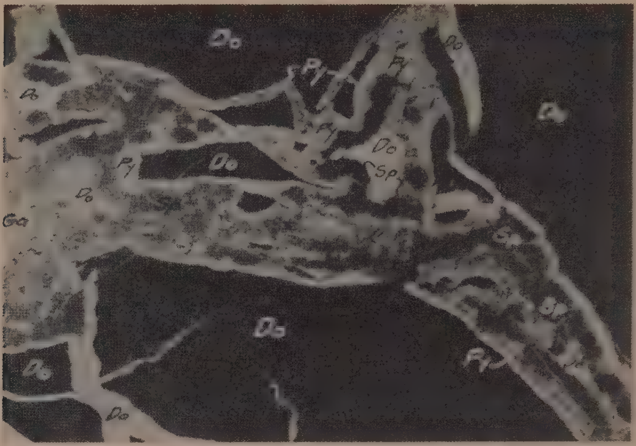
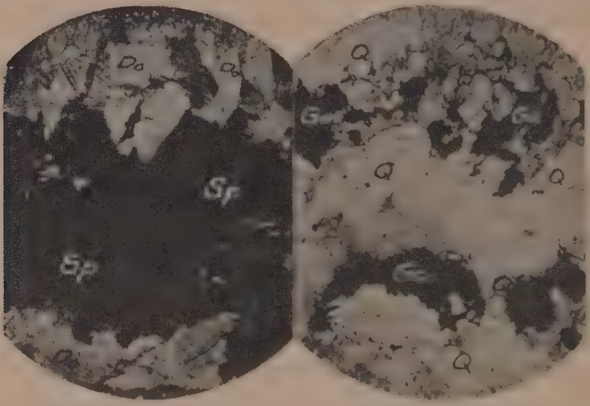


FIG. 1. Black dolomitic limestone (Do) from Austinville, Va., showing irregular banded veins of dolomite (Do), sphalerite (Sp), pyrite (Py) and galena (Ga). $X=0.8$



2A 2B

FIG. 2A. Photomicrograph across a vein of Fig. 1 showing metasomatic relation between the dolomite (Do) and sphalerite (Sp). $X=12$.

FIG. 2B. Photmicrograph showing some quartz (Q) and galena (Ga) bands of Fig. 3. in which the galena has replaced some of the quartz. $X=12$.

and pyrite in the center. It is not only clear that the dolomite has been replaced by the sulphides, but the residual areas of the carbonate shown within the sulphides indicate that the replacement has been more extensive than a megascopic examination indicates.

The beautifully banded ores from Clausthal, Germany, are quite well known and a specimen of one of these is shown in Fig. 3. This consists of bands of quartz, sphalerite and galena. The width and distinctiveness of the bands decrease toward the center of the vein.

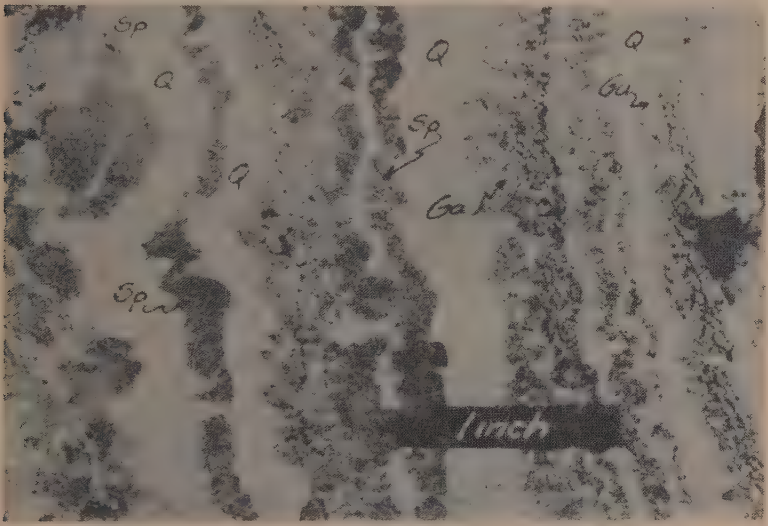


Fig. 3. Banded specimen of quartz (Q), sphalerite (Sp) and galena (Ga) from Clausthal, Germany.

Fig. 2B shows a photomicrograph of two bands of galena and parts of three bands of quartz and it seems evident from these that the galena has in part replaced the quartz.

It appears to the writer that the relationship between the bands of this specimen may be explained on the basis that the banding is the result of rhythmic fractional crystallization[2] and the accompanying physico-chemical changes. In the phase where the process changes from the crystallization of one band to the deposition of another, the supersaturation of the mineral of the first band has been reduced close to the saturation point where the solid phase of the mineral and the solution are close to a state of equilibrium.

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[2] Shaub, B. M., The Cause of Banding in Fissure Veins: *Am. Mineral.*, vol. 19, pp. 398–399, 1934.

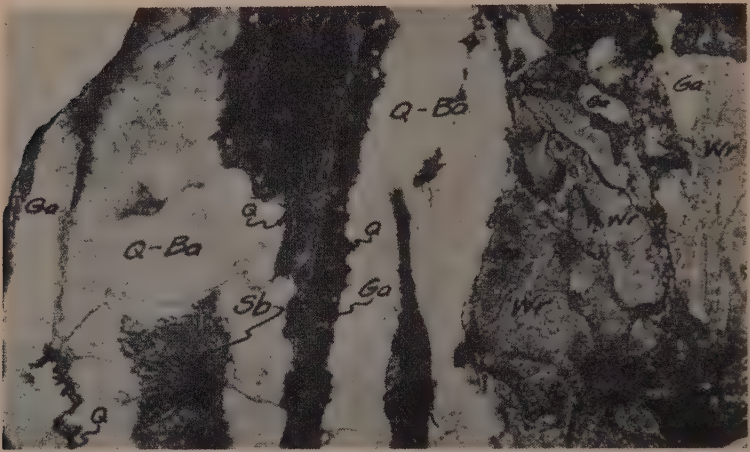
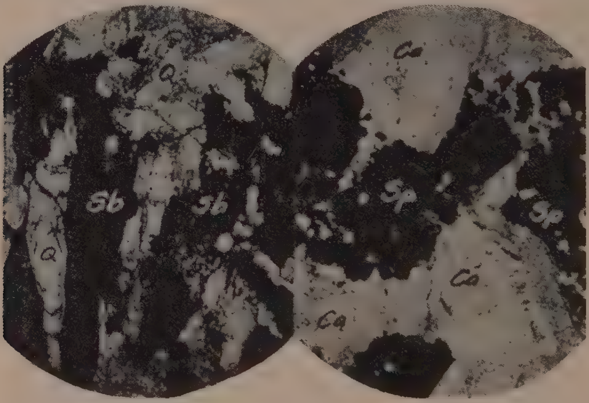


FIG. 4. Brecciated vein specimen from Przibram, Czechoslovakia, showing fragments of galena (Ga) and wallrock (Wr) cemented by quartz (Q) and a slush-like intergrowth of quartz and barite (Q-Ba). Stibnite (Sb). $X=0.35$.



5A 5B

FIG. 5A. Photomicrograph from specimen of Fig. 4. showing metasomatic relation between stibnite (Sb) and quartz (Q). $X=12$.

FIG. 5B. Photomicrograph from specimen of Fig. 6 showing metasomatic relation between sphalerite (Sp) band and carbonate (Ca).

When the solute which crystallizes to form the succeeding band becomes sufficiently supersaturated to cause it to crystallize, its deposition follows rapidly causing a liberation of heat and changes in the composition of the solution. These together with other physico-chemical changes occurring at or near the contact of the crusts introduces a metastable condition conducive to replacement at the junction of the bands.

An interesting specimen from Przibram, Czechoslovakia (Fig. 4), is a brecciated vein consisting chiefly of galena, quartz, barite and stibnite. Among the last minerals to crystallize were quartz and stibnite near the center of the irregular bands of quartz and barite which have a slush-like textured intergrowth. The radial stibnite clearly replaces some of the quartz as is shown in Fig. 5A where it can be seen that the zoned crystals of quartz have been dissolved to unequal depths.

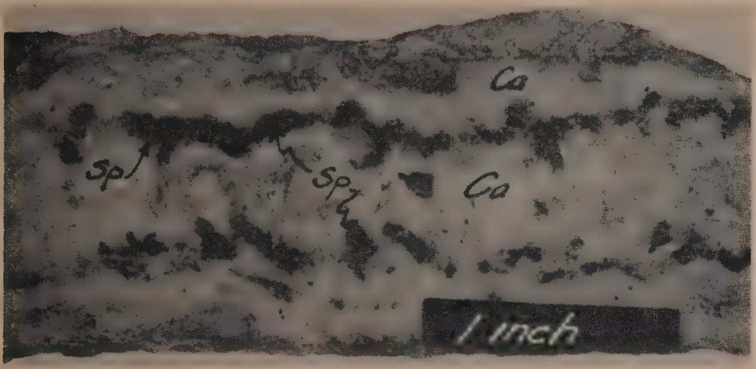


FIG. 6. Small carbonate (Ca) vein from Brad, Transylvania showing, two irregular although symmetrical bands of sulphides, chiefly sphalerite (Sp).

A specimen from Brad, Transylvania (Fig. 6), shows irregular bands of sulphides symmetrically arranged in a carbonate gangue. The first carbonate to crystallize shows fine bands of white colloid-like inclusions immediately preceding the sulphides which have replaced the carbonates along both contacts leaving many residua of replacement in the sulphide areas (Fig. 5B) which do not appear to follow shear zones.

The cause of the metasomatic relationships of the minerals in the specimens from Austinville, Przibram and Brad is believed to be more or less analogous to that described above for the Clausthal specimen with the exception that in the latter the physico-chemical conditions were favorable for rhythmic banding.

Additional examples with their variations might be quoted, but it would seem that the foregoing are sufficient to bring out the point mentioned in the beginning of this paper.

While the process described was noticed chiefly in specimens from mesothermal deposits, it was also observed, but to a far lesser extent and degree, in deposits formed in shallower zones where the solutions are less concentrated.

ACKNOWLEDGMENTS

The writer wishes to acknowledge his indebtedness to professor Heinrich Ries for many valuable suggestions and criticisms.

CRYSTAL CAVITIES IN LAVAS FROM THE HAWAIIAN ISLANDS

KINGSLEY C. DUNHAM, *Harvard University.*

In the *American Mineralogist*, volume **18**, 1933, pages 369–385, there appeared an article by the writer, bearing the above title, and setting forth the results of a mineralogical and paragenetic study of material collected by the late Professor A. S. Eakle. During 1934 this article was the subject of some correspondence from Dr. H. T. Stearns of the United States Geological Survey, who is stationed on Maui, in the Hawaiian Islands. Dr. Stearns has been able to supply valuable information bearing on the field relations of the lavas in which the cavities occur. With his permission, extracts from his letters are quoted below.

Material from three principal localities was studied: Moiliili Quarry, Honolulu, Oahu; Alexander Dam, Kauai; and the Lanikai Hills, whose locality should have been stated as Oahu and not Hawaii. Some of the Lanikai material was erroneously labeled as "near railroad station"; this should have been "near radio station."

Dr. Stearns agrees with the writer's conclusion that the minerals at the first of these localities originated from the nepheline-melilite basalt flow in which they are found, and writes as follows: "The Moiliili Quarry is in the terminal margin of the Sugar Loaf lava flow, probably the youngest on Oahu. This lava was erupted after the dissection of the Koolau dome, and at the quarry rests on emerged reef limestone. The basal water table lies most of the time just below the basalt, which is about 50 feet thick at this point, but in wet weather the water table rises into the lower part of the basalt. The Sugar Loaf flow displaced Manoa Stream and buried the lower part of the flat floor of Manoa Valley. It is possible that the high volatile content of this particular flow is partly due to the wet ground over which it spread, because without a doubt it shows more primary vein-development than any other flow on the island. However, the nephelite basalts in the Koolau Range, Oahu, were all rich in volatiles as shown by the zeolites in them and the feeble development of pegmatitoid structure in the Maunawili and Kamanaiki basalts."[1]

Dr. Stearns further calls attention to important differences between the Moiliili and Lanikai occurrences: "The flows at Lanikai (basalt of Kailua volcanic series) are typical lava flows of the Kailua dome greatly altered by hydrothermal activity. These flows were apparently poured out as normal aa and pahoehoe flows and based on analogy with the other Oahu flows probably solidified without the development of any secondary minerals." Quoting from page 89 of Bulletin 1: "It is known that the Kailua flows were either directly under or close by the summit caldera of the Koolau Volcano, hence the secondary minerals may have been deposited by ascending vapors during the history of this caldera. If cavities in the breccia can be found containing the same minerals as in the cavities in the lava, then subsequent rather than concurrent hydrothermal action will be established. If it can be proved that the minerals were deposited as each flow cooled then some special condition must have existed during their cooling not common to the other basalts of this type. Possibly the Kailua lavas were erupted under the sea, yet the lack of pillow lava and interbedded marine deposits dictates against such a hypothesis."

Thus the vein and cavity fillings of the Sugar Loaf basalt at Moiliili may be very different in mode of origin from those in the Kailua lavas at Lanikai. I have identified calcite and chlorite in a few thin sections of breccia sent to me for examination by Dr. Stearns indicating that some minerals were deposited in the breccia after it accumulated; but the typical zeolites of the Lanikai flows, epistilbite, laumontite, heulandite, and ptilolite were not found. However, Dr. Stearns reports that the breccia outcrops are very massive and weathered, making it difficult to obtain specimens which might contain cavities. The origin of the Lanikai minerals can only be determined, therefore, by further study of the breccia and the flows.

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[1] See also, Stearns, H. T. and Vaksvik, K. N., Geology and Ground-Water Resources of the Island of Oahu, Hawaii: *Div. of Hydrography*, T. H., Bull. **1**, pp. 189–198, 1935.

Attention was directed to the somewhat altered condition of the Lanikai basalts in the article (page 379). The alteration takes the form of rather feeble chloritization. Providing that it can be convincingly demonstrated that this effect is confined to the vicinity of the latest eruption center, and is not due to superficial alteration, then it will be necessary to agree with Dr. Stearns' hypothesis that it is due to hydrothermal activity. Since it is hardly likely that zeolites and minerals associated with them could survive hydrothermal alteration, it is necessary to grant either that they were produced from the solutions which brought about the alteration, or were introduced later.

Turning in conclusion to the general question of the genesis of zeolites in basaltic lavas, there can be little doubt that at least two modes of origin are possible. They may represent the last residual products of the flow magma, as at Moiliili and Alexander Dam; or they may be produced during the hydrothermal alteration of the lavas by solutions from some source outside the lavas, as in the Michigan copper region, where this process has been convincingly demonstrated. In the one case their substance is derived from the magma which produced the rock in which they are found; in the other, it came for the most part from the rock itself.

THE OCCURRENCE OF SPHALERITE AT ELLSWORTH, OHIO

Gerald U. Greene, *Cleveland, Ohio.*

Ellsworth, Ohio, is renowned for the selenite crystals which were formerly found there. Small selenite crystals are still to be had, but unfortunately most of them have the crystal faces corroded to such an extent that they are indistinguishable. While seeking for selenite the writer noticed numerous ironstone concretions lying in the bed and along the banks of the small stream which flows past the clay bank in which the selenite crystals are found. A short journey up-stream disclosed the source of part of the concretions. They were found, in situ, in a bed of shale near the water's edge. This bed is evidently not the only source since they are found in the stream above the point where this particular bed is exposed. Upon breaking a few of the concretions the writer was astonished to find sphalerite in the shrinkage cracks in the center. A few were found to contain barite alone, others contained barite and sphalerite. Still others contained calcite and sphalerite. The calcite is generally sandy although a few very small crystals were found on a drusy surface; in others, under a microscope, small rhombs were apparent. Small crystals of pyrite were found in a few of the concretions, generally in the interstitial fillings, but in one case, they were in the walls of the concretion.

Apparently when the concretions were formed they contained considerable moisture. As they gradually dried, the shrinkage cavities developed and cracks formed reaching to the surface. Then the waters bearing calcite and some zinc compound, probably the sulphate, seeped into the crevices. The calcite deposited when CO_2 was lost and the zinc may have been precipitated by the hydrogen sulphide formed in the shale, or possibly by reduction of the sulphate in solution by reducing gases from the shale.

Samples of the shale were tested for sulphates and for zinc but neither were found present. The stream in which these concretions occur is about 1 mile south of Ellsworth and may be reached from that place by following Highway No. 45 south from Ellsworth until the road crosses a bridge over the stream. The concretions may then be found by following the stream for a short distance east of the road.

BOOK REVIEW

THE ARCHITECTURAL, STRUCTURAL AND MONUMENTAL STONES OF MINNESOTA. George A. Thiel and Carl E. Dutton. The University of Minnesota Press, Minneapolis, Minnesota, 1935. Price \$2.50. IV+160 pages 12 plates and 78 figures.

This attractive and well illustrated book on the stone industry in Minnesota, which now has grown to such proportions that it is the second in value in the mineral products of the State, is a welcome contribution to this field of geology. The purpose, apparently, was to draw the attention of architects and building contractors to the fact that more than fifty distinct varieties of architectural and monumental stones are quarried and fabricated in Minnesota. As earlier reports have described in detail the geological structures and history of the State, these portions are not stressed, emphasis being placed on the descriptions of the various types of stone and the location of the quarries. Chapters also are included on the physical properties of building stones in general and the various methods employed in preparing the material for the market. Numerous chemical analyses and physical data of the stones described increase the scientific value, while the twelve colored plates which reveal in a striking manner the textural and color variations, greatly enhance the general appearance of the text.

W. F. H.

THE MINERALOGICAL SOCIETY OF AMERICA

SIXTEENTH ANNUAL MEETING

Clarence S. Ross, *President*
Paul F. Kerr, *Secretary*

New York, New York
December 26–28, 1935

Preliminary List of Papers

To be presented Thursday, December 26, 1935 after the business session at 1:30 p.m., on Friday after 1:30 p.m. and on Saturday after 9:30 a.m. in the Jade Room of the Waldorf-Astoria Hotel, Park Avenue at 50th Street.

Clarence S. Ross—*Presidential Address*, **Mineralization in the Virginia Titanium deposits.**

Waldemar T. Schaller—**The Origin of Kernite and Borax in the Kramer Borate Field, California.**

————**The Chemical Composition of Sepiolite, (Meerschaum).**

Charles Palache—**Experiments in Mounting Minerals for Exhibition.**

————**Babingtonite from Westfield, Massachusetts.**

W. A. Tarr and W. D. Keller—**Dickite in Missouri.**

T. L. Walker—**Determination of the Mineral Composition of Mine Dust by Means of X-rays.**

J. W. Greig, H. E. Merwin and E. Posnjak—**Separation Planes in Magnetite.**

C. B. Slawson—**High Iron Tourmaline from Marquette Iron Range.**

T. L. Walker and A. L. Parsons—**How to Make the Public Observe and Think in the Mineral Gallery.**

C. B. Slawson and M. V. Denny—**The Teaching Museum, an Aid to Class Instruction.**

John W. Gruner—**Hydrothermal Alteration of Montmorillonite to Feldspar at 245° C. and 300° C.**

————**The Probable Identity of the Structures of Greenalite (Mesabi Range) and Iron Serpentine.**

————**Some Notes on the Structure of Stilpnomelane.**

SAMUEL GORDON—New Cases for the Display and Storage of Specimens.

ALFRED C. HAWKINS—Calcite Crystals from North Plainsfield, New Jersey.

A. E. ALEXANDER—The Refractive Indices of Natural Resins.

AUSTIN F. ROGERS—A Tabulation of Crystal Forms and Discussion of Form-Names.

————Mineraloids.

————The Small Laboratory Museum Collection.

H. P. WHITLOCK—The Mineral Museum and the People.

C. R. TOOTHAKER—Mineralogy in the Commercial Museum.

GEORGE W. MOREY AND EARL INGERSON—The Melting of Danburite.

LLOYD W. STAPLES—Microchemical Methods in Determinative Mineralogy.

DONALD M. FRASER—Shearing Action in the Durham and Reading Hills, Pennsylvania.

M. J. BUERGER—The Crystal Structure of Berthierite.

————The Crystal Structure of Cubanite.

————The Crystal Structure of Valentinite.

————The Crystal Structure of the Arensopyrite Group.

————The Ordered-disordered Transformation in Arsenopyrite.

HARRY BERMAN—Outline of a Classification of the Silicates.

M. A. PEACOCK—On Roselite and the Rule of Highest Pseudo-Symmetry.

W. E. RICHMOND, JR.—Crystallography of Livingstonite.

C. S. HURLBUT, JR.—Differentiation in the Shonkin Sag Laccolith.

C. D. WEST –Immersion Liquids of High Refractive Index.

J. C. HAFF—The Dikes of Cape Nedick, Maine.

R. J. HOLMES—An X-ray Study of Allemontite.

E. N. GODDARD—Deposits of Radioactive Cerite near Jamestown, Colorado.

J. F. SHAIRER AND N. L. BOWEN—Pseudowollastonite and Wollastonite Solid Solutions with Diopside and Akermanite.

TOM W. BARTH—Crystallography of the Vivianite Group.

JEWELL J. GLASS—Anorthite from Duke Island, Alaska.

A. H. PHILLIPS AND H. H. HESS—Chemical Composition and Optical Properties of some Calcic Plagioclases.

————Variations in Plagioclases, Pyroxenes, and Olivines in the Stillwater Igneous Complex.

H. W. Morse and J. D. H. Donnay—**Optics and Structure of Three Dimensional Spherulites.**

E. H. Watson—**Alteration of Gabbro near Philadelphia, Pa.**

George Tunell and C. J. Ksanda—**Relationship Between the Structural and Morphological Elements of Krennerite, Calaverite and Sylvanite.**

A. N. Winchell—**A Third Study of Chlorite.**

Lloyd Fisher—**Minerals in the Bates Limestone, Lewiston, Maine.**

R. E. MacAdams—**The Accessory Minerals of the Wolf Mountain Granite, Llano County, Texas.**

Bennett Frank Buie—**A Peculiar Form of Differentiated Igneous Intrusion.**

Correction

At the bottom of page 695, Greek gamma erroneously stands in place of Greek alpha.

The Cleveland Mineralogical Society founded on July 24, 1935, held its first meeting on October 2. The Society holds monthly meetings in the mineralogical room of the Department of Geology, Western Reserve University. The officers of the Society are:

George C. Whitaker, President
Harold S. Booth, Vice-President
A. S. Furcron, Councillor
Robert H. Long, Secretary-Treasurer

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